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NOTE ON THE VARIATION OF THE SPECIFIC HEAT OF MERCURY WITH TEMPERATURE. EXPERIMENTS BY THE CONTINUOUS-FLOW METHOD OF CALORIMETRY.[1]

By H. T. Barnes and H. L. Cooke.

SINCE the communication to the Royal Society in 1900, of the work of one of the authors on the specific heat of water, it has been possible to continue the experiments by the continuous-flow method of calorimetry to the case of mercury. These measurements, which include an interval of temperature between 0° and 90° C., have been carried out with essentially the same apparatus as previously used for water, and with the same electrical standards. The first determinations which were made by mercury by this method were made by Professor Callendar and one of the authors during the summer of 1897, just previous to the Toronto meeting of the British Association. The results then obtained with our preliminary apparatus were entirely revised and recalculated three years later. It was the intention of one of the authors to include them in his paper on the specific heat of water since they afforded a most satisfactory verification of the theory of the method. Deeming it advisable, however, to redetermine the value of the specific heat and to extend the experiments over as large a range of temperature as possible with more refined apparatus, it was decided to reserve the publication until later. These results, which were ob-

[1] Paper read before the British Association, Belfast, 1902.

tained from our preliminary experiments, stand in close agreement with the authors later results, the error being less than 1 part in 1,000, although carried out with different electrical standards, and a calorimeter differing materially in design from the one recently employed.

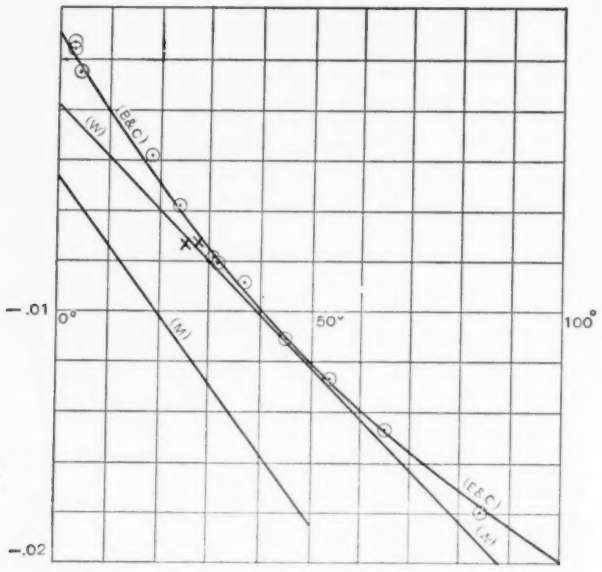

Fig. 1.

⊙. Observations of Barnes and Cooke, 1892. ×. Observations of Callendar and Barnes, 1897. *B. & C.* Formula proposed by Barnes and Cooke. *W.* Formula proposed by Winkelmann. *M.* Formula proposed by Milthaler.

The present series of experiments was made with a calorimeter in every way similar to the " water " calorimeter described by Professor Callendar and one of the authors (B. A. report, 1898) with the exception that the flow tube was smaller in bore. The rest of the apparatus was essentially the same, with a few minor changes.

PRELIMINARY RESULTS.

These results obtained in 1897, we reproduce here through the courtesy of Professor Callendar who was one of the observers at that time. They were obtained with jacket circulation system, without temperature regulator, so that observations taken at the temperature of the laboratory only could be successfully carried out. The calorim-

eter employed had a flow tube 1 meter long and 1 mm. in diameter coiled in a spiral as described by Professor Callendar (Phil. Trans., Vol. 199, 1902). The thermometers were pair *A* described by one of the authors (Phil. Trans., Vol. 199, 182, 1902, Sec. 3c). The Clark cells were S_1 and S_5 and the resistance standard was one of the manganin coils described in Section 3b, *supra*.

The only three determinations made at room temperature are as follows:

Date.	Mean Temperature.	Js	s
July 9, 1897	25.0	.13898	.033174
" 14 "	27.4	.13899	.033177
" 19 "	28.0	.13900	.033179

Recent Results.

The later results were obtained with improved apparatus. The calorimeter had a flow tube about 1 mm. in diameter and 45 cm. long. The thermometers were pair *E*.

The mica-frame resistance standards and Clark cells X_2 and X_{11} were used. Redeterminations were made of the value of the resistances in terms of the standard platinum-silver coils in the possession of the laboratory, which showed that they had remained unchanged to 1 in 100,000 since the series of tests taken for the measurements for water, and already described. The Clark cells were found to have lowered a little in value since 1900, and a correction was necessary in order to reduce to the mean of a number of new cells. The history of these original crystal cells, made in 1895, to which X_2 and X_{11} belong, shows that from comparisons with new cells made from time to time, they have steadily lowered in value. A new comparison was also made to several Weston cadmium cells. There is no reason to doubt that the values assumed for the electrical standards are the same as those assumed in the measurement of the specific heat of water, to much better than 1 in 10,000. The thermometers were also recalibrated several times, as well as further determinations made of the box coil corrections. Hence, even assuming that any error exists for the values assigned to the units used in the calculations for water,

the specific heat of mercury may be expressed from these measurements in terms of water, and any possible error eliminated from the relative value. Since also the same apparatus has been used, and as far as possible the same experimental arrangements systematic sources of error in the method are to a large extent avoided.

The absolute values of the thermal capacity of mercury are given in the following table for different temperatures, calculated by the method already described by one of the authors.

The results are in terms of the nitrogen thermometer and are uncorrected as yet for the temperature gradient in the flow tube as described by Professor Callendar.

Since this correction is small, and is nearly balanced by the correction to the standard hydrogen scale, the results will not be changed much by its application, and the variation with temperature will remain practically unaffected.

Mean Temp.	Js	$S(J=4.1891)$.	Formula.
2.85	.140056	.033435	.14003
2.93	.140085	.033440	.14002
4.42	.139927	.033405	.13996
18.37	.139459	.033291	.13939
24.52	.139182	.033224	.13915
31.68	.138890	.033156	.13889
32.14	.138873	.033151	.13888
32.41	.138846	.033141	.13887
36.59	.138753	.033121	.13873
45.00	.138447	.033050	.13847
53.39	.138225	.032997	.13822
65.22	.137942	.032929	.13791
83.89	.137479	.032818	.13752

In Fig. 1 is given a plot of the observations the vertical scale being the value $\frac{Js - 0.140}{0.140}$. The preliminary results are also included.

It will be seen that the specific heat decreases with rise in temperature, suggesting that portion of the curve for water between 10° and 20°.

Results over a wider interval of temperature could not be conveniently taken with the present apparatus. We purpose continuing

the work to much higher temperatures immediately, in order to trace the course of the curve as the boiling point of the mercury is reached.

The equation representing the change of Js and shown by the curve in Fig. 1, reads:

$$Js_t = Js_0 - 4.462 \times 10^{-5}t + .0157 \times 10^{-5}t^2$$

where

$$Js_0 = .140154.$$

The value of the specific heat in terms of water has been calculated, taking the value of J equal to 4.1891 for a thermal unit at 15.5°, which was the temperature recommended by Griffiths at the Paris Congress in 1900 as being suitable for the selection of the thermal unit.

The temperature expression of the specific heat reads:

$$S_t = S_0 - 1.074 \times 10^{-5}t + .00385 \times 10^{-5}t^2,$$

or

$$\frac{S_t - S_0}{S_0} = -.000321t + .0000115t^2$$

where

$$S_0 = .033458.$$

This gives for the temperature coefficient at any temperature t the expression,

$$\frac{d}{dt}\left(\frac{S_t}{S_0}\right) = -.000321 + .0000230t,$$

and for the average change per degree at 50°, the value — .0000069.

Comparison to the Work of other Observers.

The value of the specific heat obtained by Regnault[1] and so universally adopted, *i. e.*, .03332 is found to be in agreement with our determination at 13.3° and very close to the value at the ordinary temperature of laboratory work. The value was obtained over a range 10° to 100° in terms of a thermal unit at 10°, and is considerably in excess of our value for the same mean temperature.

[1] Pogg. Ann., 51, 44, 1840; 51, 238, 1840.

Experiments to determine the variation with temperature indicated an increase in specific heat with increasing temperature.

Winkelmann[1] carried out an extensive series of experiments by the method of mixture, to determine the temperature coefficient and was the first to show that the specific heat decreased as the temperature increased. This result being so exceptional at the time and so contrary to the results for other liquids, the author was inclined to regard it as doubtful until he finally verified the first experiments by a second series, in which he eliminated certain sources of error. Two ranges of temperature were taken, the first between 20° and 50° C. and the second between 26° and 142° C. The average variation from these measurements was found to be .0000069. No absolute measurements were made, but the value obtained by Regnault was assumed.

The formula proposed by Winkelmann is shown in Fig. 1; this reads:

$$S_t = S_0 - .0000069t.$$

The remarkable agreement with the average change from our determinations is shown very clearly in the figure, a total decrease of 2 per cent. between 0° and 100° being given both by Winkelmann's results and our own.

The position of the curve in the figure shows that the temperature at which Winkelmann assumed Regnault's value, which in one case was the mean from 16° to 20° and in the second case from 13° to 25° is very nearly equal to the temperature at which our value is exactly equal to Regnault's, *i. e.*, 13.3° C.

Pettersson and Hedelius[2] obtained .033266 between 0° and 5°, .033262 between 5° and 16°, .033300 between 5° and 26° and .033299 between 5° and 36° C. These results were all expressed in terms of a thermal unit for water at 0°.

The measurements were repeated more accurately by J. Milthaler[3] who used a similar method to the previous investigators, *i. e.*, the method of mixture. This author verified Winkelmann's results and

[1] Pogg. Ann., 159, 152, 1876.
[2] Jour. für Prak. Chem., 24, 136, 1881.
[3] Wied. Ann., 36, 897, 1889.

showed that the specific heat apparently decreased with rise of temperature, the average decrease from his measurements being .0000092, which is somewhat greater than Winkelmann obtained.

The formula proposed by Milthaler is shown in the figure (M). The slope of the curve is about the same as the slope of our curve at the low temperature, but since Milthaler supposed this formula to apply as high as 200° its agreement for the low temperatures is more a matter of coincidence. The position of the line in the figure shows that the value of Pettersson and Hedelius which he assumed, is too small at 0° compared to our values, but this value will be increased when corrected to a thermal unit for water at 15.5° instead of 0° and will then be brought into much closer agreement.

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SOME OPTICAL PROPERTIES OF IODINE. II.

BY WILLIAM WEBER COBLENTZ.

II. THE ABSORPTION OF SOLID AND LIQUID IODINE.

1. *Solid Iodine.*

IN all this work commercial, "resublimated," iodine was used. The films were made by melting large iodine crystals between pieces of plate glass or rock salt. For the region of the spectrum up to 2.7 μ the radiometer-spectrometer arrangement used was the one employed for the iodine solutions. On account of the difficulty in obtaining a large uniform film of iodine, the specimens to be examined were placed between the slit F_1 and the source. They were mounted in vertical ways which kept them parallel to the slit and at the same time prevented lateral shifting. This necessitated the shifting of the source, which decreased the deflections, so that a more sensitive fiber, giving a period of 1.5 minutes, was used throughout all the succeeding work. The pressure in the radiometer was about .02 mm.

In all, four films were examined, the thickness varying from 0.015 mm. to 0.055 mm. All but the last were transparent, the color of an incandescent lamp filament by transmitted light being similar to that of the dense iodine solutions in CS_2. The absorption of the glass plates was found, and corrections made. From the resulting curves, Fig. 12, it will be seen that the absorption rapidly decreases for all films and becomes quite constant from 1.2 μ to 2.7 μ. The absorption of the thinnest film becomes zero at about 1.0 μ. Table VII. gives the transmission for different wavelengths.

For the region beyond 2.7 μ the entire apparatus was rearranged. To avoid sudden changes of temperature, the whole apparatus was enclosed in tin boxes. The drift of the zero reading was never

very large, but was unsteady until after the radiometer had been enclosed and packed in wool. The movable arm F_1 was protected

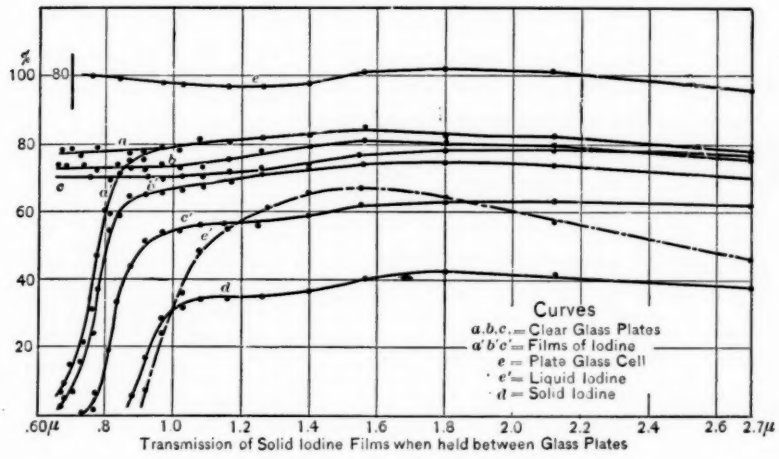


Fig. 12.

$a' = .015$ mm., $b' = .020$ mm., $c' = .025$ mm., $d' = .055$ mm., $e' = .062$ mm.

by several shields to avoid stray radiations. The whole is shown in Fig. 13, in which N is the source, C the film, S_1, S_2 the shutters, and P the prism. The lower figure, a, is a tin-foil covering for the inner window, to prevent electrification of vanes. Later on it was found that part of this electrification came from the exhaust pump. This was prevented by placing a tube containing gold foil in series with the radiometer.

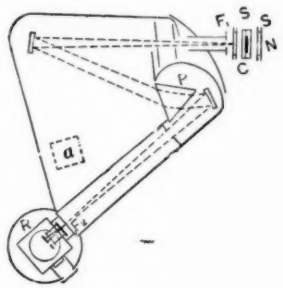


Fig. 13.

The windows of the radiometer were of rock salt, cut parallel to the cleavage planes to avoid polishing. The radiometer slit subtended an angle of 10′ of arc $= .13\mu$ at 1μ.

A 70 mm. rock salt prism having an angle of 59° 55′ 47″ was used instead of the carbon bisulphide prism of the previous determinations. The surfaces were in a fairly good condition. The prism was securely mounted on its stand, and when not in use was covered and protected from moisture by drying material.

TABLE VII.

Transmission through Solid and Liquid Iodine. (*Glass Included.*)

Wave-lengths in μ.	Solid Films.					Liquid.
	Thickness of Films in mm.					
	Clear Glass.	Transmission, $I_\epsilon \div I_0$.				
		$a = 0.015$.	$b = 0.020$.	$c = 0.025$.	$d = 0.0055$.	$e = 0.062$.
.66 μ	78					
.67	78	7	2			
.68	78	10	6			
.70		14	8			
.73	78	21	16	1		
.76		33	24	2		
.78		47	38	7		
.81	78	60	54	19		
.84		70	59	34		
.88	78	75	64	44	5	
.92		77	65	51	17	7
.97	79	79	67	53	29	24
1.02	79	81	67	55	32	36
1.08	81	82	68	56	34	48
1.16	81	80	69	57	35	55
1.26	82	82	71	57	35	57
1.40	83	83	73	54	37	59
1.56	84	85	74	62	40	62
1.80	83	83	74	63	43	63
2.10	82	83	74	64	41	58
2.70	78	77	70	62	38	46

Calibration. — The prism was set at minimum deviation for the sodium lines, by using a telescope, and calibrated by observing the absorption bands of quartz, found by Nichols[1] at 5.3 μ, 6.25 μ, 6.68 μ and 8.1 μ, and the emission bands of the bunsen acetylene flame, found by Paschen[2] at 1.9 μ, 2.7 μ, 4.4 μ, and 6.62 μ. The quartz plate was 2 mm. thick, and was cut perpendicular to the optic axis. The results are shown in Fig. 14, where wave-lengths and circle readings are plotted. The work was greatly facilitated by computing the approximate positions of the various absorption bands. The minimum deviation for different wave-lengths was then computed by

[1] E. F. Nichols, PHYSICAL REV., Vol. 4 (1897).
[2] Paschen, Wied. Ann., 52, p. 209 and 53, p. 334 (1894).

using the indices of refraction found by Rubens & Trowbridge,[1] by Paschen,[2] and by Langley.[3] When changed to circle readings and

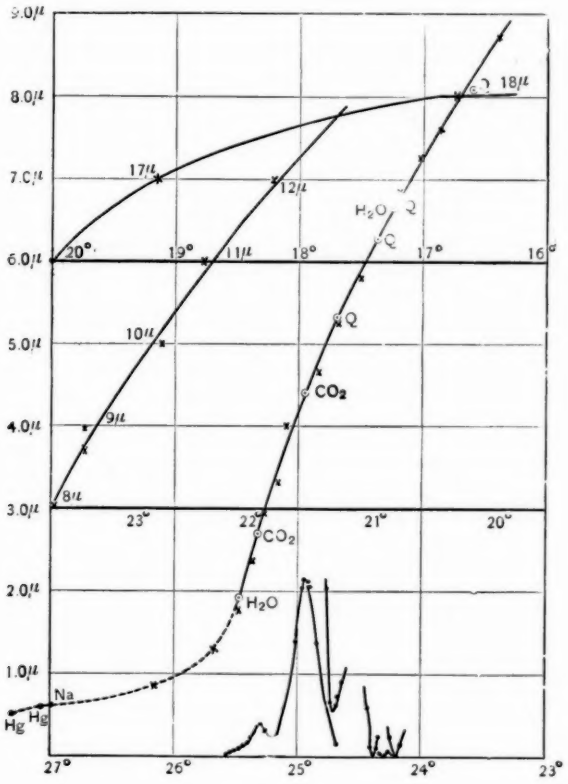


Fig. 14.

plotted on the calibration curve (represented by * * *), they are seen to follow the latter very closely. Finally the march of the radiation through the prism was computed, thus finding the actual deviation of the rays. The error introduced by not keeping the prism at minimum deviation for different wave-lengths is shown in Table VIII.

[1] Rubens & Trowbridge, Wied. Ann., 61, p. 224 (1897), also Rubens, Wied. Ann., 53, p. 267 (1894).

[2] Paschen, Wied. Ann., 53, p. 337 (1894).

[3] Langley, Annals Astrophys. Obs., Vol. 1, p. 258.

TABLE VIII.

Angle of prism 59° 57′ 15″.

Wave-length.	Computed Minimum Deviation.	Computed Actual Deviation.	Correction, $\Delta\lambda$.
1.0 μ	39° 55′.6	39° 55′.6	0.000 μ
2.945	39 16 .3	39 16 .9	+ 0.032
7.22	38 1 .9	38 3 .4	+ 0.063
12.0	35 50	35 55 .3	+ 0.150

The actual error agrees well with the theory as worked out by Wadsworth.[1]

Beyond 10 μ the calibration was continued by computing the minimum deviation settings for the different wave-lengths. Since no absorption bands of iodine occur beyond 8 μ the errors in wave-lengths introduced by using minimum deviation settings are of minor importance.

For a source of radiation an acetylene flame was used for the shorter wave-lengths. This was very unsatisfactory beyond 7 μ. For measurements at longer wave-lengths the "glower" of a Nernst lamp, and subsequently the two "heaters" of the same lamp were tried. These last proved to be the most satisfactory for the long wave-lengths. Beyond 16 μ, with a slit-width of 1 mm., these "heaters," placed at a distance of about 10 cm. from the slit, gave a deflection of 6 mm. on a scale placed at a distance of 1.5 meters.

The films were melted between plates of rock salt, which were ground but not highly polished. Considerable difficulty was experienced in making films of even fairly uniform thickness and free from air bubbles, so that the chief error lies in not knowing the true thickness. This work was done during warm weather, and on account of evaporation the transparency of the film varied from day to day. To explore the entire spectrum required about four hours. In order to lessen the time and to avoid any appreciable variation in the transmission that might occur during this interval, thus making one region of the spectrum more transparent relatively to

[1] Wadsworth, Astrophysical Journal, 2, p. 264 (1894).

the remaining part, the method of exploration adopted was to take a few readings for a few points throughout the entire spectrum, and also take the mean of a great many readings at a certain region of the spectrum, — *e. g.*, at 7 μ. Consequently curves *b* and *c*, Fig. 15, represent most accurately the absorption band region at 7 μ,

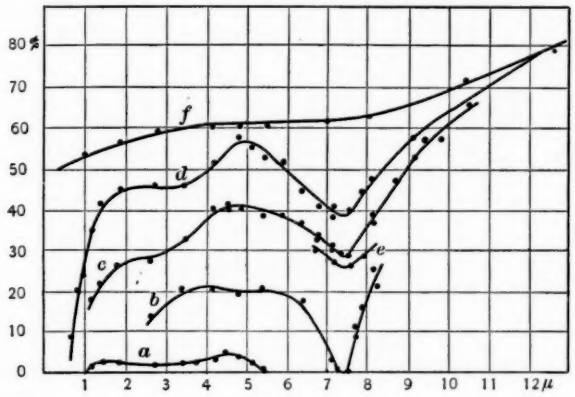


Fig. 15.

Solid iodine films. $a = .15$ mm., $b = .09$ mm., $c = .06$ mm., $d = .027$ mm., $f =$ rock salt.

while *d* shows the region of short wave-lengths. The latter also verifies the absorption spectrum of the films between glass plates. Curve *e* indicates the increased transparency of *b* after standing three days. The rock salt used for the plates came from Louisiana. The plates contained impurities, probably gypsum. The transmission curve of two of these plates, used to determine curve *d*, is shown in curve *f*, Fig. 15. It will be noticed that the transmission increases steadily from 54 per cent. at 1.0 μ to 66 per cent. at 9 μ.

Results. — An absorption band was found, Fig. 15, which begins at 6 μ and extends to 10 μ, with a maximum at about 7.4 μ. The curve is asymmetrical, with its steeper side towards the long wave-lengths where the transparency rapidly increases. Beyond 12.5 μ, where deflections were very small (an acetylene flame having been used), measurements became difficult on account of the drift of the radiometer with the temperature of the room; but the mean of a series of 14 readings, made at a time when this disturbance was least

marked, gave a transmission of 77 per cent., which, on eliminating the absorption of the rock salt plates, makes this region transparent.

Table IX. gives the transmission for the different wave-lengths

TABLE IX.

Transmission of Films of Solid Iodine and Rock Salt.

Wave-length λ =	Transmission.			
	Layer *a* .15 mm.	Layer *b* .09 mm.	Layer *c* .06 mm.	Layer *d* .027 mm.
.87 μ				20.4
1.0				24.4
1.15			18.0	35.2
1.4	1.7		21.8	42.0
1.85	2.4		25.4	45.0
2.7	2.5	13.5	28.7	45.5
3.45	2.1		32.4	46.2
3.73	2.8	20.8		
4.17	3.8	20.8	40.3	52.0
4.50	4.9	19.4	41.6	58.0
4.80	4.4		40.1	55.7
5.42	0.8	20.5	38.1	53.0
5.66	0.0		39.1	
5.90				51.5
6.36		18.0	37.2	45.0
6.75			34.6	41.0
7.14		2.9	31.0	38.0
7.33		0.9	29.6	
7.54		0.0	29.3	40.0
7.93		9.0	29.0	44.3
8.13		16.5	39.5	
8.70			47.6	
9.40			57.5	59.5
9.80			58.0	
10.5			66.0	77.0
12.5				

2. *Liquid Iodine.*

In this work, the greatest difficulties met with were those found in providing a suitable cell, which would not be attacked by the iodine when in a liquid state. The different parts of the cell had to fit well, and had to be subjected to great pressure to prevent the vapor from escaping. All cements available were attacked by the iodine. Cells were made by blowing flat

bulbs of glass, by flattening tubing, by using mica, etc., but each was found defective. Finally two pieces of plate glass were selected, thick enough to withstand a high pressure. In the face of one of them a flat cavity *b* was made by grinding and polishing, which, when the two plates were clamped together as shown in Fig. 16, gave a cell of suitable depth. In the other plate a deeper circular pocket (*a*) was ground, which, when the plates were placed together, connected with *b* in the manner shown. In the figure, which is about two thirds of the actual size, *g*, *g*, are the glass plates (each 5 mm. thick), *w* is a shield of hard wood, and *t* is a thermo-junction for the determination of the temperature.

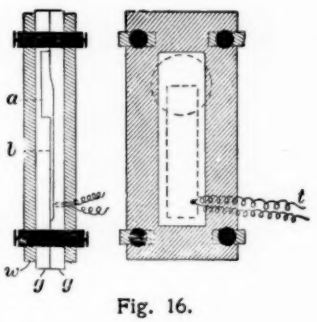


Fig. 16.

The grinding was done on a power drill press, using an extension arm, which gave freedom of motion in all directions in the plane of the glass plate. The grinding tool was a small lead cylinder, with which washed emery and water were used. The polishing was done by covering the lead with beeswax, and applying rouge. In this manner a quite plane, highly polished surface was produced.

The cell was only 0.062 mm. deep, and entirely enclosed. It was filled by placing in the reservoir, *a*, solid iodine crystals, which, when melted ran down into the cell.

The cell was mounted in vertical ways, between the collimator slit and the acetylene flame, Fig. 5. The spectrometer apparatus used was the same as that for the study of the solid iodine.

(*a*) *Transmission at a Variable Temperature.* — The cell was placed in an oven and heated far above the melting point of iodine — in one case to 155° C.

The cell was then placed before the slit, and allowed to cool. The rate of cooling and the period of the radiometer was such that any measurable variation in absorption with variation in temperature could have been detected if present. No such variation was found.

The fall of temperature was measured by means of a galvanometer and a thermal element of No. 30, B. S., German silver-copper

wire. The latter was placed in a small hole drilled in the cell wall, and was held fast by means of tinfoil, covered with plaster of paris.

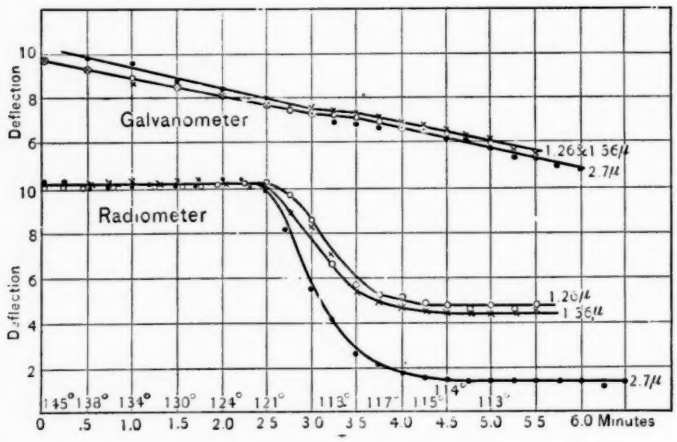


Fig. 17.

The transmission through liquid iodine with variation of temperature was studied by this method at 1.26 μ, 1.56 μ, 2.7 μ. The curves in Fig. 17 serve best to show the result. Here the ordinates represent deflections of the galvanometer (upper curve), and of the radiometer (lower curve). The abscissæ represent the time in minutes, also the temperatures as indicated by the thermo-element. From these curves it is evident that the apparatus in this form had a considerable temperature lag, for the melting point of the iodine must correspond to the sudden drop in the radiometer deflections. From Fig. 17 it may be seen that this is several degrees too high. In order to check this interpretation of the discrepancy, the thermo-element was subsequently placed in a thin glass tube, and sealed in a glass bulb containing a larger quantity of iodine, Fig. 18. Conditions as regards pressure were thus quite similar to those in the experiment. The melting point as obtained from the curve of cooling of this apparatus was 114°.1 C., which is in close agreement with previous determinations.[1]

Fig. 18.

[1] Ostwald, Allgemeine Chemie, gives 113°.9.

Considering the fact that the thermo-junction is at the side of, and not in contact with, a layer of iodine 0.062 mm. thick, one would expect such a lag. Nevertheless, in spite of the lag of the thermo-junction the experiment just described serves perfectly to establish the fact that the transmitting power of liquid iodine does not change materially with temperature between about 145° and the melting point for any one of the three wave-lengths selected.

It also shows that the transmission to be the same for all these regions (1.26 μ, 1.56 μ, and 2.7 μ), and much greater than that of solid iodine for those wave-lengths.

It will also be seen from the curves that the transmitting power of the solid iodine varies but little for several degrees below the melting point.

(*b*) *Transmission at a Constant Temperature.* — After it had been found that the temperature had no effect on the transmission, the spectrum of liquid iodine up to 2.7μ was further explored by heating the cell until the iodine had melted, and then placing it before the collimator slit. The iodine remained liquid for over two minutes, which gave ample time to make a series of measurements at a given region of the spectrum. Since the absorption is so different in the two states, there was no difficulty in knowing when crystallization occurred.

In Fig. 12 curve *d* represents the transmission through the solid film and the glass cell. Iodine contracts on cooling so that it no longer fills the cell, being only 0.055 mm. thick, while the depth of the cell was 0.062 mm. In its liquid state (curve *e*, which represents the mean of two series of observations) the transparency rapidly increases; the transmission curve crossing that of the solid at about 1.0μ. It becomes a maximum at 1.5μ, where the transmission is about 90 per cent. greater than that of the solid, and then gradually decreases to 2.7μ, where the difference in transmission is only about 2 per cent.

All the observations have been corrected for the deflection due to the hot glass, which at no part of the spectrum was greater than 3 mm.

In Table VII. is given the transmission through liquid iodine and cell.

(*c*) *Transmission through Turbid Media.* — A thin film of iodine is far more transparent to the visible rays when liquid than when solid. The appearance of an incandescent lamp filament, by light transmitted through a solid film, is similar to that which it presents when viewed through the CS_2 solutions; but through a thick layer the filament appears much broadened and blurred, probably due to internal reflection.

Ångström[1] has shown that the absorption of media containing discrete particles follows the same law as that for perfectly homogeneous bodies, so long as the particles are small in comparison to wave-lengths. He found that, in the case of long wave-lengths, the absorption is like that of a homogeneous medium.

At the time when the absorption of films of solid iodine was measured the sensitiveness of the radiometer was slowly decreasing from day to day. This did not affect the absorption measurements. The application of Ångström's work to the relation of transmission to thickness, with reference to the blurring effect just mentioned, was not thought of at that time. To apply this test, the radiometer must have the same sensitiveness for all films. By means of the exhaust pump the sensitiveness had been kept approximately the same for all films. Selecting measurements where the direct deflections were the same for the different films, and applying them in the formula $\log \frac{I_0}{I_n} = n \log \frac{I_0}{I_1}$, where I is the intensity, represented by the radiometer deflections, and n the ratio of the thickness of the two films compared, the results agree sufficiently to conclude that for long waves (not tested beyond 2.7 μ), the solid films absorb like an optically perfect medium. Beyond 2.7 μ the films were between plates of rock salt which were not plane, consequently the thickness of the films is not known accurately enough for this work.

3. *Comparison of the Absorption of Iodine as a Film, and in Solution.*

A comparison of the absorption of the CS_2 solutions and the films, Figs. 9 and 12, shows a great similarity between them. The thinnest film of the solid is transparent in the infra-red, like the CS_2

[1] Ångström, Wied. Ann., 36, p. 715 (1889).

solution. Furthermore, the thickest solid film and the saturated solution are very similar for the short wave-lengths. The question then arises whether or not the transparency of the CS_2 solutions is due to the small quantity of iodine dissolved.

A computation of the thickness of iodine in a 20 mg. per c.c. solution of iodine in CS_2 (if the iodine were deposited in an even layer), shows that it is about 0.07 mm. The saturated solution would make a much thicker film, at least 0.1 mm. thick. Nevertheless the CS_2 solution is perfectly transparent in the region where much thinner films of solid iodine show considerable absorption.

Rubens,[1] using a cell with fluorite windows, has measured the absorption of CS_2 up to 3 μ, and has found that it is almost entirely transparent. A comparison of the absorption of glass in Fig. 12 and the absorption of CS_2 + cell in Fig. 9 shows that the bisulphide is almost transparent.

It will be interesting to learn the action further out in the infra-red

III. Pleochroism.

The unequal transmission of the two polarized rays through a doubly refracting crystal was first observed in tourmalin, by Biot[2] in 1819. This was followed by the publication of a list of some sixty dichroic crystals, by Brewster.[3] During the latter part of the century our knowledge of selective absorption has been extended by the researches in the ultra-violet, by Agafonoff[4] and in the infra-red by Merritt[5] and others.

An examination of the literature on the optical properties of iodine shows that, if mentioned at all, little more than the crystalline form, and the ratio of the axes of symmetry is given. This, however, is what one would expect, considering the physical state in which this element is found. Nothing is known about the position of the optic axes. Consequently in the following work the expressions "maximum" or "minimum extinction" have been used.

[1] Rubens, Wied. Ann., 45, p. 260 (1892).
[2] Biot, Bulletin de la Soc. Philomathique, 109 (1819.)
[3] Brewster, Phil. Trans., p. 11 (1819).
[4] Agafonoff, Archives des Sci., Phys. et Nat., t. 2, p. 349 (1896).
[5] Merritt, Phys. Rev., Vol. 11, p. 424 (1895).

A transparent film of iodine shows that, when the Nicol prism is turned for maximum extinction, the transmitted light is deep red, while for minimum extinction the light is greenish-yellow.

The iodine was melted between pieces of plate glass, and usually crystallized in long narrow films, in all directions. This crystalline structure is not likely to be due to stresses in cooling. The glass cell used in the absorption work, and the prism used in measuring indices of refraction, exert no pressure on the iodine when cooling. Yet the double refraction was present just as in the films between glass plates. Films of cyanine did not show double refraction.

For this work glass plates showing little or no double refraction were selected. After melting the crystals, and the solid film had formed, there were always air bubbles present, through which polarization in the glass could be detected if present. A region was then selected where the film was uniform and no double refraction appeared in the glass.

It may not be out of place to mention that the glass showed temporary double refraction immediately after cutting. A fan-shaped effect could also be produced by drawing a sharp file across the edge of the plate. Placing a plate, thus treated, between crossed Nicols the light would be restored, but would disappear again at the end of three or four minutes.

For the visible part of the spectrum the horizontal slit spectrophotometer, already mentioned, was used. Since there was considerable difficulty in obtaining uniform films sufficiently large, it was found most convenient to place the crystal with its ong side parallel to the slit, and then rotate the polarizer.

For a source of polarized light a large Foucault prism was employed.

The crystal used in the spectrophotometric work was extremely thin, and by ordinary light appeared yellowish-brown in color. From previous measurements of thicker films its thickness was estimated to be 0.005 mm., or even less than this. In convergent polarized light it had a greenish tint, and gave uniform extinction over an area of about 1×10 mm. All other thicker films were too opaque for photometric work.

The infra-red region was explored by means of the radiometer and CS_2 prism arrangement used in I. For an analyzer the Fou-

cault prism, already mentioned, was used. It was mounted on the collimator arm between the slit F_1, Fig. 5, and the first mirror. It was necessary to rotate the prism, since a large uniformly polarizing film was not obtainable. The film of iodine was thicker, 0.012 mm., but was still transparent. It was introduced between the source and the slit F_1 of the collimator.

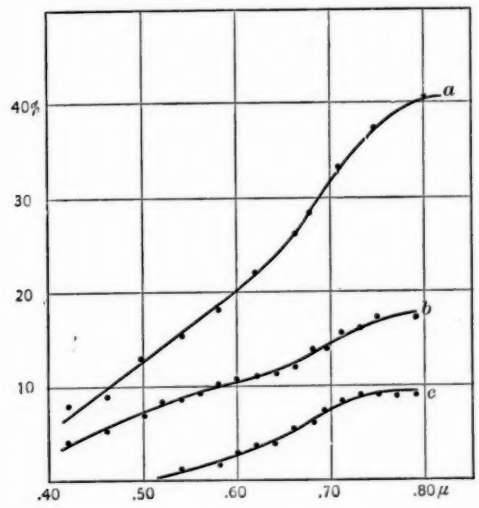


Fig. 19.

An examination of the transmission curves, Fig. 19, shows that for maximum extinction (curve *c*), where the color of the film is tinged with red, the absorption becomes complete at the end of the yellow. On the other hand, for minimum extinction (curve *b*) light is transmitted throughout the spectrum.

Curve *a* gives the transmission of ordinary light through the same film.

These curves are quite similar to those obtained for the alcohol solutions.

In the infra-red the absorption is interchanged. Here, for minimum extinction, the transmission is less (curve, *b'*) throughout the spectrum than for maximum extinction (curve *c*). In Fig. 20 curve *d* gives the absorption of unpolarized light through a film 0.015 mm. in thickness, while *b'* and *c'* show the absorption of the polar-

ized rays. In each case the curve has been corrected for the absorption of the glass.

The curves in Fig. 20 are connected by dotted lines simply to show their trend. This is permissible since both were transparent so that

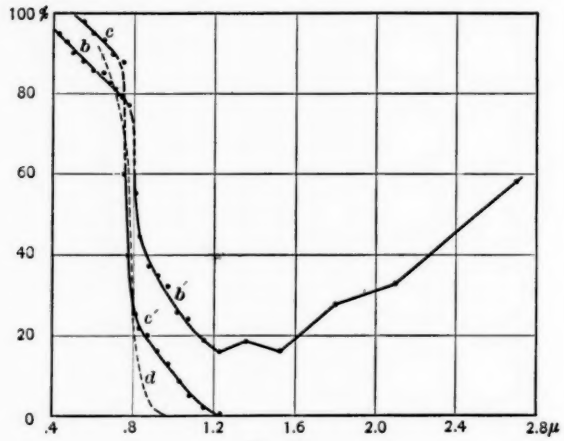


Fig. 20.

the position of maximum and minimum extinction could be distinguished. For a proper comparison, the curves must be corrected for thickness, which, on this scale, would make those for the visible spectrum quite insignificant.

Extreme accuracy was not possible by this method. As indicated by Merritt[1] the action of stray light from the prism must be eliminated by using two spectrometers in series. Since the radiometer is fixed, such an arrangement is not so easily used as with a bolometer. The loss of polarized light at the prism could have been avoided by placing the polarizer and the film of iodine between the second mirror and the radiometer slit. This likewise was not practicable on account of the shifting of the spectrum, due to inaccuracies in setting the apparatus, such as turning the polarizer. Since all the films used were so dense that nothing could be determined about the position of the axes of the crystal, it seemed sufficient to arrange the apparatus as indicated.

The irregularities in the curves are, at least in part, due to errors in making the observations, and since they are not very marked, it

[1] L. c., p. 433.

may be assumed that stray radiations did not seriously affect the results.

This is confirmed in part by a comparison with the absorption of ordinary light, by a slightly thicker film (curve *d*, Fig. 20), which becomes transparent at 1.1 μ. These curves, Fig. 20, have been corrected for the absorption of the glass and the Foucault prism.

IV. Anomalous Dispersion of Solid and Liquid Iodine.

The remarkable absorbing power of iodine vapor was discovered by Le Roux[1] in 1860. He found that only the red and violet rays were transmitted, and that of these the red is the more refracted, contrary to what takes place in the ordinary cases of refraction.

The indices of refraction for the red and violet rays for iodine vapor were measured by Hurion[2] in 1878. He found for the red, *C* line, $n = 1.0205$, and for the violet, C_1 line, $n = 1.019$. From these, assuming that the refracting power of a body is independent of its physical state, he found for solid iodine, $n = 1.89$ for the red, and $n = 1.83$ for the violet.

In 1886 Dazebrink[3] found the anomalous dispersion of iodine in CS_2.

1. *The Indices of Refraction of Solid Iodine.*

In finding the refractive indices for solid iodine, the chief difficulties consisted in obtaining plates sufficiently plane-parallel, and in making prisms which were transparent enough, yet at the same time free from rills due to contraction and crystallization.

The size of the glass plates was about 2 x 5 x .5 cm. They were made from a good quality of plate glass, which had a slight yellow tinge.

The prisms were made by placing several large iodine crystals between two plates, and clamping one edge (previously ground straight), with a flat-jawed metal clamp, having a long handle.

The wedge thus formed was held above a Bunsen flame, and when melting began, a thin piece of cardboard was inserted in the open edge, and the whole clamped tight. It was found that cooling

[1] Le Roux, Ann. de Chemie et de Physique (3), tom. LXI., p. 285 (1861).
[2] Hurion, Jour. de Physique, 7, p. 181 (1878).
[3] Dazebrink, Beiblätter, Bd. X., p. 493.

the whole quickly in cold air gave the best results. In all this work the glass plates had to be perfectly clean in order to get a thin edge which was free from holes or rills. Unlike cyanine, iodine is brittle, so that it was impossible to break off the glass and yet keep a smooth refracting edge. In addition to this, evaporation must be contended with. This, however, was of minor importance since the work was performed during zero weather.

By proceeding as just indicated a prism could be made very quickly, and after several hundred trials five were obtained, of different sizes and having different angles and refracting qualities. The angles of the prisms were from 8′ to 30′. The refracting edges were from .5 cm. to 2.5 cm. in length.

For producing the spectral lines to be measured, cored carbons, filled with the salts of Li, Na and Th elements, were used. An Arons mercury lamp was also used. The spectrum was produced by means of a flint-glass prism.

TABLE X.

Prism.	Angle, α.	Deviation, δ.	n for Li_α.
1	30′.2	28′.5	1.95
2	27 .5	29 .3	2.07
3	24 .0	24 .5	2.06
4	8 .4	7 .9	1.94

The refractive index was measured by placing the iodine prism between the one of flint glass and the observing telescope. A portion of light thus passed through the glass undeviated, while another part passed through the iodine and was deviated. Two images were therefore visible in the telescope, and by means of the micrometer eye-piece their distance apart could be measured. Then from the known length of the telescope, 24.5 cm., and the calibration of the filar micrometer, 1 turn = .243 mm., the angular deviation was computed. This gave the tangent of the angle. The angle of the prism was found by measuring the thickness of the wedge inserted, and its distance from the refracting edge. The error introduced by so doing was small, since the thickness of the wedge inserted could be measured quite accurately, while its dis-

tance from the refracting edge was great in comparison, and a slight variation in the latter affected the results in the third decimal place. The indices of refraction were computed from the well-known formula $n = (a + \delta) \div a$ and are given in Table X.

The large variation in the refractive indices is to be explained in part by the fact that in prisms 1 and 4 the wedges were of paper, which is difficult to measure, *e. g.*, in No. 4 the thickness was only 0.106 mm. In prisms 2 and 3 the wedges were of hard material which kept a sharp edge.

Furthermore, the transparency and definition must be considered. Thus No. 3 had a refracting edge of about 2.5 cm. and gave excellent definition. In No. 2 the edge was of about the same length but was full of air bubbles, and its definition was poorer. The others were full of air bubbles and rills, while the refracted band was blurred for No. 4, and almost invisible for No. 1. A better result for solid iodine is given on a subsequent page.

2. *Liquid Iodine.*

The hollow prism for the liquid iodine was made by grinding and polishing a wedge in a piece of plate glass by the same method as for the absorption cell. The refracting edge was quite straight, as shown by the straight interference bands, and although not highly polished, the transmitted spectral lines were well defined. In fact, a more highly polished prism was rendered useless on account of the lack of planeness caused by excessive polishing. In making the hollow wedge the plate of glass is rendered prismatic. This causes a deviation of the spectral lines in the opposite direction to that by the iodine prism. Hence the deviation of each line by the empty prism was carefully measured, and added to that produced by the iodine prism.

The same spectrometer arrangement was used as in the preceding work. The angle of the prism was computed from the measurement of the distance between the deviated and undeviated Sodium band, produced by the light passing through the refracting edge and the plane glass, respectively, and the refractive index of glass, $n = 1.52$. For a mean of 26 readings the angle was $4'.37$. In the same manner two images were visible by the reflection of

light from the collimator slit, one from the refracting edge, the other from the plane glass. The distance between them, measured with the filar micrometer, gave the tangent of twice the angle. The mean of 21 readings gave an angle of 4′.43, which is in close agreement with the preceding measurement. This cell was also used for the indices of refraction of solid iodine.

The results for both solid and liquid iodine are given in Table XI. The same formula was used as in the preceding work. The refractive indices of the Li_α, Li_β and Na lines are given for the value of the angle α_1 of the prism obiained by reflection and by refraction. In II. the refracting edge was much denser and the Li_β line could not be seen.

TABLE XI.

I. Telescope, focal length 24.5 cm.

	Deviation of Glass Wedge. Each a Mean of 10 Readings.	Deviation of Liquid Iodine. Mean of 26 Readings for Each Line.	Total Deviation $= \delta$.	Liquid.		Deviation of Solid Iodine. Mean of 22 Readings.	Solid.
				n by Reflection.	n by Refraction.		n by Reflection.
Li_α.	.126 mm.	.216 mm.	4′.67	2.05	2.07	.217 mm.	2.07
Li_β.	.151	.170	4 .37	1.99	2.00	.170	2.00
Na.	.153	.161	4 .27	1.96	1.98	.160	1.96

II. Telescope, focal length 24.3 cm.

Li_α.	Mean of 7 readings.	4′.81	2.07	2.08
Na.	Mean of 11 readings.	4 .36	1.98	1.99

It is interesting to note in the table that the deviation δ for the solid iodine is the same as that for the liquid, although the readings were made exactly a week apart, the iodine having been melted several times during this interval.

Considerable difficulty was experienced in obtaining a solid prism by this method, on account of the small angle which prevented an even crystallization of the solid iodine.

The sources of error here are the determination of the angle of the prism at the refracting edge, and the rigidity with which the two plates are held together. Unlike cyanine, which is somewhat viscous when melted, the iodine flows freely like water, and, in order to prevent its going beyond the refracting edge, the plates must be subjected to considerable pressure. Thus, in one series of measure-

ments it was found that all the indices were very much smaller than those obtained previously. An examination of the prism showed that the iodine had forced itself between the plates, and decreased the effective refracting angle.

The green thallium band could not be measured on account of the absorption of the prisms. An Arons lamp was used as a source for the yellow Hg lines, which appeared very faint. Only a few readings were made, which were very uncertain, and gave a refractive index of 2.08. An attempt was made to use polarized light (Foucault prism), but no successful measurements were obtained on account of the increased absorption.

Professor A. C. Gill, of the Department of Mineralogy, kindly examined several films of solid iodine. All but the one used in III. were too thick for the purpose. This one was extremely thin. Assuming the thickness to be 0.005 mm. and that the dispersion does not change with the normal order of the interference colors, the double refraction $(\gamma - \alpha)$, is at least 0.5.

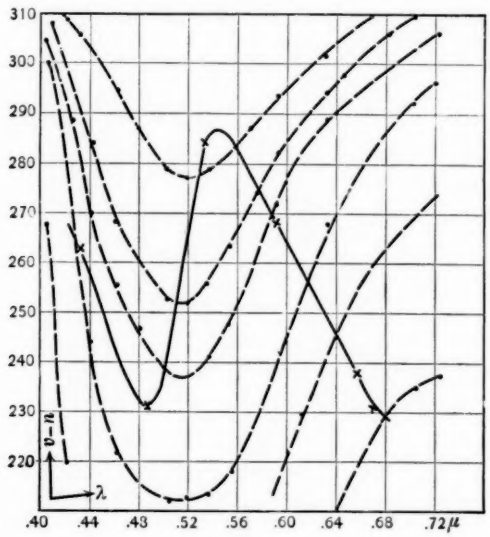


Fig. 21.

In Fig. 21 the curves show the relation between the transmission and anomalous dispersion of CS_2 solutions of iodine. The ordinates represent the differences of the refractive indices, v and n, of the

iodine solutions and of carbon bisulphide. The data for the dispersion curve are due to Dazebrink, and have been taken from Wüllner's Experimental Physik, Vol. 4, p. 202. According to Dazebrink[1] the shifting of λ_m for the different concentrations, is of no consequence, is often opposed to theory, and is also to be found in solutions of colorless salts.

The values of the refractive indices agree well with those found by Hurion.[2] He assumed that the refractive power of a mixture is the sum of those of its constituents (Wüllner's formula),[3] and found for solid iodine:

n for red, C line, $= 2.07$.
n for blue, G line, $= 1.98$.

Since this formula holds only where the constituents have undergone no chemical change, one would infer that the CS_2 solutions of iodine have that property, and that the change in the transparency of iodine in the solid state and in solution is yet to be explained.

It will be noticed that the refractive indices are much smaller when computed by Hurion, by assuming the refracting power of a body to be independent of its physical state. Since at a high temperature iodine vapor dissociates from I_2 into 2I it is possible that the discrepancy is due to this fact.

SUMMARY.

1. The absorption of iodine in solution of carbon bisulphide and ethyl alcohol was measured to $\lambda = 2.7\ \mu$. For the visible spectrum a horizontal slit spectrophotometer was used, while the infra-red was explored by means of a radiometer.

In the visible spectrum the CS_2 solutions have a strong absorption band, maximum at about $0.515\ \mu$, while that of the alcohol solution lies in the ultra-violet. The latter solution becomes dichroic for weak concentrations.

All the CS_2 solutions become transparent beyond $1.1\ \mu$ while the alcohol solutions vary in absorption with the concentration, and, like the solvent, become opaque at $1.4\ \mu$.

[1] Dazebrink, Beiblätter, 10, p. 494.
[2] Hurion, Jour. de Phys., 7, p. 181 (1878).
[3] Wüllner, Pogg. Ann., 133, p. 1.

2. The transmission of solid iodine was found to 13 μ. Two absorption bands exist, one in the visible spectrum, the other at 7.4 μ.

Liquid iodine was explored to 2.7 μ. It was found that its absorption does not depend on the temperature, but is less than that of solid iodine. A comparison of the thickness of iodine, as a film, when in solution of CS_2, and as a solid film shows that the total quantity of iodine in a saturated solution would make a film almost ten times thicker than the thinnest, transparent, solid film. Yet the solution is transparent, while the same thickness of iodine, in a solid film, is quite opaque. For the long waves the relation of transmission to thickness of solid iodine fulfils the law for optically perfect media with a degree of approximation equal to that of the knowledge of the thickness of the films used.

3. The two polarized rays are unequally absorbed. One is more transparent to the visible rays, while the other is more transparent in the infrared.

4. Like the vapor and the CS_2 solutions, solid and liquid iodine shows anomalous dispersion. The indices agree well with those computed from solutions for spectral lines lying close to those measured, and are the same for iodine in a solid and a liquid state.

This investigation was made under the direction of Prof. E. L. Nichols to whom the writer expresses his obligations for the interest he has taken in the work, his timely suggestions and the liberal supply of apparatus made accessible. He is also grateful to Prof. E. Merritt for his friendly criticisms during the various phases of this investigation.

THE PHYSICAL LABORATORY OF
CORNELL UNIVERSITY, May, 1902.

THE RADIANT EFFICIENCY OF THE MERCURY ARC.

BY WILLIAM C. GEER.

IN the year 1860 Way[1] observed that an intense light was produced when an electric current was allowed to flow through a fine thread of mercury which was falling from an upper reservoir to a lower one. He had this "mercurial electric light" on the mast of a yacht off the Isle of Wight where its brilliant radiation was observed from a distance of many miles. The newspapers of the day commented upon its intensity and suggested it as a means of artificial illumination.

The interest thus aroused in the discovery naturally stimulated investigation and as a result many patents[2] have been issued, in this and other countries, whose main specifications describe a lamp for obtaining an arc between mercury terminals. Rapieff in 1879 took out a British patent (No. 211, 1879) for an inverted **U**-tube having the ends dipping into mercury, and the arc playing either in air or in a vacuum. Rizet in 1880 obtained a French patent (certificate d'addition of March 20, 1880, for Rizet's patent No. 132,426 of August 27, 1879). The design was similar to the above while the **U**-tube is filled with nitrogen. Langhans in 1887 obtained a German patent (No. 45,880) for a **U**-tube with legs filled with any metal or metalloid. By far the most interesting and thorough attempt to render this principle of commercial value has been made by Cooper-Hewitt[3] with what he calls a mercury "vapor lamp." He has patented a large number of designs.

None of these mercury vacuum tubes has proved to be practicable as a means of artificial lighting and consequently they have failed of commercial success. However, the mercury arc has rendered valuable service to pure science. The green lines, produced by

[1] Chem. News, 2, 167, 1860.

[2] von Recklinghausen, Zeit. f. Elektrotech., 23, 492, 1902.

[3] Cooper-Hewitt, Elect. World and Eng., 37, 679, 1901; 38, 503, 1901; 39, 80, 1902.

this means, are employed in spectrometric work as a source of monochromatic light of high intensity which can be maintained for a long time, when properly cared for, and which is comparatively easy to produce. The device commonly used in the production of the arc is some form of the tube, or "lamp," described by Arons[1] in 1892 and in 1896. Many slightly different designs have been made by Lummer[2] and others. These lamps all embody the same principles, viz., a U tube of some sort having the two legs filled with mercury, through the ends of which platinum wires are sealed, the whole being exhausted as far as possible.

From the published results of the work of Arons[3] and the fact that the arc gives out such a brilliant light, one would infer that the radiant efficiency, or the ratio of the luminous radiation to the total radiation, must be large. The following paragraphs will describe the results of an attempt to measure the efficiency of that part of the radiation of the mercury arc which was transmitted through the glass tube within which it was formed. Any radiation from the glass itself was carefully corrected for and left out of account in the calculations.

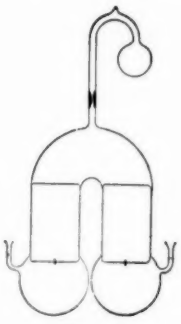


Fig. 1.

The vacuum tube used, Fig. 1, was of the form designed by Arons. The distance between the mercury terminals was about 2 centimeters while the arc itself measured some 5 centimeters. The electrical energy was supplied by a 110-volt direct-current circuit.

The measurements were made according to the method described by Professor Merritt[4] and frequently used in this laboratory. The calculations of the efficiency were based on the deductions of Professor Nichols,[5] who found that the radiant efficiency of a source of luminous energy is approximately expressed by the equation,

$$E = \left(1 - \frac{e'}{a'}\right)\frac{a'}{A}$$

[1] Wied. Ann., 47, 767, 1892; 58, 73, 1896.
[2] Zeit. f. Instrumentenk., 15, 294, 1895; 21, 201, 1901.
[3] Op. cit.
[4] American Journal Science [3], 37, 167, 1889.
[5] PHYSICAL REVIEW, 11, 215, 1900.

in which A is the total energy of the source being measured, a' is the energy transmitted by a cell of distilled water, and e' is the energy transmitted by a cell of water and a cell containing a saturated solution of iodine in carbon disulphide.

The radiation from the lamp was allowed to fall upon the face of a thermopile and the first throw of the galvanometer read.[1] This reading is proportional to the total radiation, A. The throw was then observed with a cell of distilled water interposed between the lamp and the thermopile, which gave the reading proportional to the luminous radiation a'. Since a portion of the longer waves is transmitted by the water, the correction reading e' was taken by observing the throw when a cell, containing a saturated solution of iodine in carbon disulphide, was interposed together with the water cell.

The value of A, taken under these conditions, does not represent the total radiation of the arc alone, for it was found that the glass tube, in which the arc was playing, became so highly heated that it emitted a very considerable radiation of its own. Even after so short a run as one minute the mercury boiled in the tube and there was danger of its destruction. The galvanometer throw, then represented the true total radiation of the arc, A, plus a large radiation of the heated glass, which may be designated d''. It was found, therefore, that no true value of A could be obtained directly by means of the apparatus at our disposal.

When one considers a curve which shows graphically the energy, in terms of galvanometer throws, that the lamp is radiating from the time the arc is started until it is extinguished and the glass has cooled nearly to its original temperature, a ready method of finding the value of A becomes evident. Such a curve is seen in Fig. 2. The arc was started with the lamp at or near the room temperature. The radiation rapidly increased in intensity, until at the end of 30 seconds it was measured by the throw d'. On the instant that this throw was reached the circuit was broken, the arc extinguished and the time of the observation recorded. This throw measured the arc radiation, A, plus that of the glass, d''. While the lamp was cooling several successive throws were taken and the time of each recorded. Thus the remainder of the curve, $b'c'$, is a time curve

[1] Merritt, American Journal Science [3], 41, 417, 1891.

of cooling of the hot glass. By extrapolation of this cooling curve to the time d an ordinate, d'', is found which evidently measures the energy of the hot glass at that time. Since the arc was broken

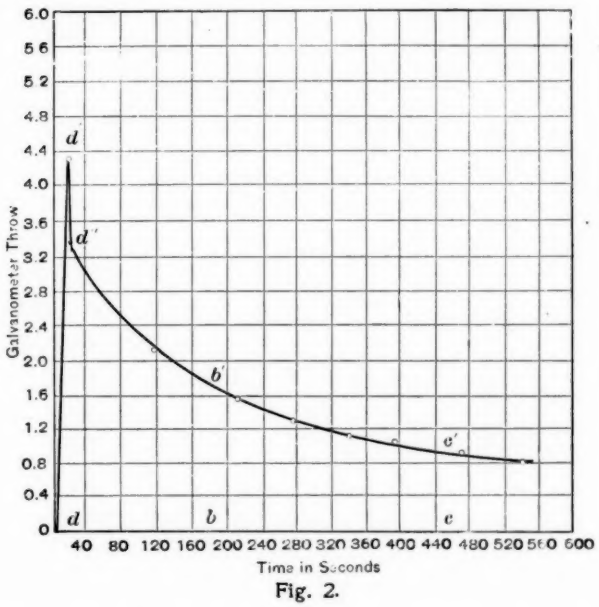


Fig. 2.

at the time d, the difference between the ordinates d' and d'' is the throw proportional to the arc radiation alone, which is the desired quantity A.

The full detail of the method is seen by a reference to Fig. 3. The frame resistance consisted of four tin-strip resistance frames which were used to regulate the current for the different determinations. The lamp was mounted in the position shown in two holes in a block of wood, one end of which was fastened to the table by means of a small hinge. It could then be tilted, by means of a cord, from the observer's position at the galvanometer telescope. The mercury then flowed from one leg to the other, thus striking the arc. The screen was of sheet iron, which also was controlled from the observer's position. The iodine solution and water were contained in plane glass cells one and one half centimeters in thickness. The thermopile, placed 25 centimeters from the lamp, was a 24-couple instrument connected to a d'Arsonval galvanometer,

Upon the table which supported the telescope were the ammeter, the voltmeter and the key for operating the chronograph relay. This key, the chronograph relay, the chronometer, which was beating two-second intervals, and the circuit breaker were connected as shown. In order to determine A, the chronometer and chronograph were put in operation and the iodine and water cells removed. The lamp was then tilted, thus striking the arc, the ammeter and voltmeter read, while as soon thereafter as possible the screen was drawn away and the first throw of the galvanometer observed. On the instant that this throw was read the key was pressed, thereby actuating the chronograph relay, which recorded the time of the observation, and actuating the circuit breaker which simultaneously

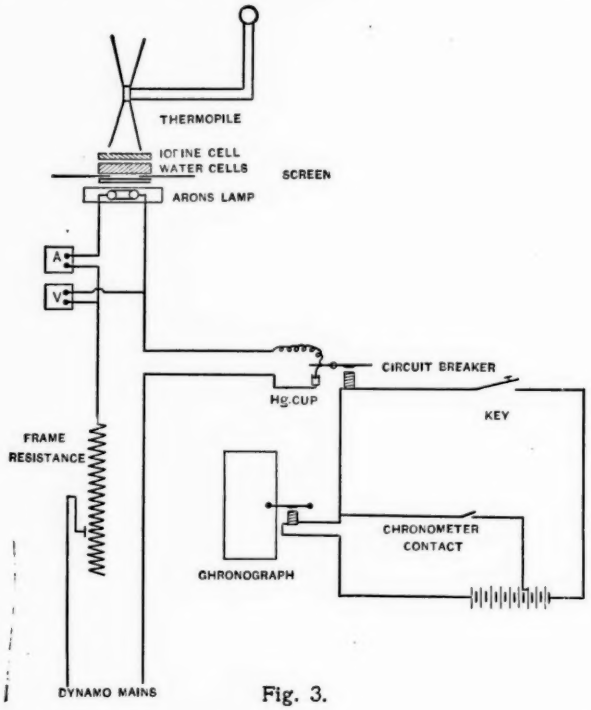


Fig. 3.

extinguished the arc. As the lamp cooled several successive throws were read, for each of which the time was recorded by pressing the key. By this means the time curve of cooling was obtained, one of which has been shown in connection with Fig. 2. On extrapola-

tion to the ordinate axis d'' was obtained. The difference between this value and d', which was the throw actually observed, gave the quantity A which was the throw proportional to the radiation of the arc alone.

No difficulty was experienced in obtaining the readings with the water cell nor with the iodine cell. When these were being read the heat waves, except the shorter lengths, were absorbed by the water. These three quantities, A, a' and e', were determined for several currents between five and nine ampères and the efficiencies for each current strength calculated therefrom. In making the readings the plan followed was to make several determinations of A, then several of a' and of e' and finally several additional determinations of A. The mean values of a' and e' were used with each value of A in calculating E from the equation given above. Lower currents were tried but the arc would not maintain during the time necessary to make a reading. With higher currents the lamp became so highly heated that the results were wholly unreliable and consequently were rejected.

An annoyance which was of common occurrence was caused by the arc going out before the first throw was read. This was especially frequent when working with the lower currents. In order to be certain that the arc was playing throughout each throw a small mirror was mounted near the telescope of the galvanometer by means of which the light from the lamp was reflected into the free eye. The breaking of the arc was at once recognized and the readings repeated until satisfactory.

TABLE I.

Time.	Seconds.	Galvanometer.		d	$1/d$
		Zero.	Throw.		
11 : 47 : 49	000	35.36	39.72	4.36	
49 : 28	99	35.60	37.72	2.12	0.472
51 : 1	192	35.50	37.06	1.56	0.640
52 : 6	257	35.60	36.90	1.30	0.769
53 : 9	320	35.60	36.73	1.13	0.885
54 : 6	377	35.60	36.62	1.02	0.980
55 : 22	453	35.50	36.42	0.92	1.088
56 : 16	507	35.60	36.42	0.82	1.220

$a'/A = 0.465$ $\qquad$ $d'' = 3.38$ $\quad 1/d'' = 0.296$

$E = 0.427$ $\qquad$ $A = 4.36 - 3.38 = 0.98$

Volts 14.5 $\qquad$ Amperes 4.75

The full data for one determination of E is given in Table I. When the reciprocals of the galvanometer throws, $1/d$, are plotted as ordinates and time as abscissas the curve of cooling is found to be a straight line from which the extrapolation is easily accomplished. The curve from the data given is shown in Fig. 4, while

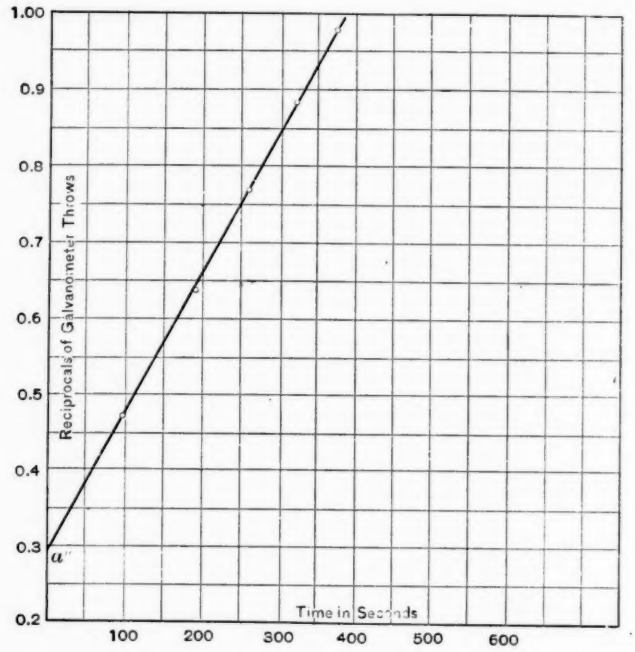


Fig. 4.

the complete curve has already been discussed, since it is seen in Fig. 2. The extrapolated intersection with the ordinate axis a'', is the reciprocal of d'', the throw due to hot glass at the instant that the arc is extinguished. A is the difference between the throw first obtained and this value d''. E is then calculated from the equation.

A summary of all the results is to be found in Table II. The separate determinations are seen to vary considerably even at the same current. This variation may be due to several causes. In the first place the arc was extremely unsteady, the cathode being in constant motion. Arons[1] states that the arc is a discontinuous

[1] Wied. Ann., 47, 768, 1892.

TABLE II.

Volts.	Amp.	$A+a''$	a''	A	a'	e'	$a'A$	E
14.7	5.06	4.53	3.18	1.35	0.534	0.030	0.396	0.374
14.7	5.06	5.66	4.44	1.22	"	"	0.438	0.414
15.2	5.08	5.72	4.54	1.18	"	"	0.453	0.428
14.5	4.98	4.87	3.77	1.10	"	"	0.485	0.458
14.9	4.98	5.12	3.76	1.36	"	"	0.393	0.371
14.7	5.00	4.68	3.64	1.04	"	"	0.513	0.484
14.7	5.03	4.59	3.59	1.00	0.456	0.0375	0.456	0.419
14.5	4.75	4.36	3.38	0.98	"	"	0.465	0.427
14.5	5.11	5.70	4.65	1.05	"	"	0.434	0.398
14.7	5.02							0.419
14.2	6.03	5.06	4.00	1.06	0.535	0.030	0.505	0.477
14.5	5.79	5.10	4.08	1.02	"	"	0.524	0.494
14.4	5.97	5.20	3.76	1.44	"	"	0.372	0.351
14.3	5.98	4.13	2.95	1.18	0.523	0.040	0.443	0.409
14.5	6.09	4.56	3.35	1.21	"	"	0.432	0.399
14.5	6.35	5.10	4.00	1.10	"	"	0.476	0.440
14.4	6.03							0.428
14.4	7.05	7.57	5.88	1.69	0.623	0.0375	0.375	0.353
14.5	7.00	5.49	4.00	1.49	"	"	0.426	0.401
14.6	7.23	5.86	4.12	1.74	"	"	0.365	0.344
14.6	7.15	6.39	5.13	1.26	"	"	0.504	0.474
14.5	7.21	5.57	3.92	1.65	"	"	0.385	0.362
14.6	6.99	4.94	3.54	1.40	"	"	0.453	0.427
14.8	7.14	5.43	3.95	1.48	"	"	0.429	0.404
14.5	6.98	4.52	3.17	1.35	"	"	0.470	0.442
14.4	7.13	4.50	3.12	1.38	"	"	0.460	0.433
14.7	7.01	5.67	4.24	1.43	"	"	0.444	0.418
14.6	7.09							0.406
14.3	8.07	4.60	3.40	1.20	0.678	0.035	0.555	0.526
14.5	8.15	5.47	4.00	1.47	"	"	0.461	0.437
14.6	8.07	6.82	5.21	1.61	"	"	0.421	0.400
14.5	8.16	4.55	2.70	1.85	"	"	0.366	0.347
14.5	8.20	5.30	3.61	1.69	"	"	0.401	0.380
14.5	8.07	5.26	4.03	1.23	"	"	0.552	0.523
14.4	8.07	6.37	4.95	1.42	"	"	0.477	0.452
14.5	8.11							0.438
14.6	8.97	5.97	4.44	1.53	0.826	0.050	0.540	0.507
14.7	9.20	7.66	6.17	1.49	"	"	0.554	0.520
14.7	9.13	6.55	4.78	1.77	"	"	0.467	0.438
14.6	8.97	9.43	7.94	1.49	0.750	0.050	0.504	0.470
14.7	8.97	5.44	3.92	1.52	"	"	0.493	0.461
14.7	9.04							0.479

one, basing his conclusion on the sound that is given by a telephone receiver when properly connected. The writer has observed that when one places his ear close to the lamp an unsteady sound of low pitch can be distinctly heard. This unsteadiness is undoubtedly one of the causes for the variation in the efficiency determinations. Then again, the mercury which distilled from the terminals condensed upon the cooler sides of the tube forming an irregular layer which absorbed considerable energy. Furthermore, the temperature of the tube at the time when the throw of the galvanometer was read varied a good deal with the different determinations, even in spite of great care. Since the total electrical energy[1] used has been found to change with the temperature of the tube, it is quite probable that the efficiency may be influenced by this cause. Also the temperature of the tube would influence the rate of cooling and as a consequence it would be possible that the extrapolated values of the hot glass deflections may be in error in some cases. These errors could not be corrected with the apparatus at hand. The mean of a large number of determinations is doubtless quite near to the true efficiency.

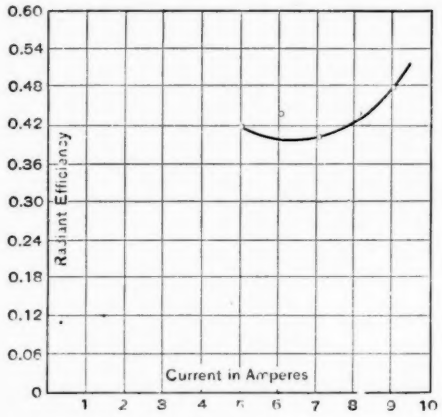


Fig. 5.

When efficiencies and currents are plotted a curve is obtained as shown in Fig. 5. From this it would appear that, in general, the radiant efficiency of the mercury arc increases with the current. In other words the intensity of the visible part of the spectrum in-

[1] Arons, Wied. Ann., 58, 88, 1896.

creases more rapidly than that of the invisible part. This does not accord with the work of Ångström on the intensity of the radiation from vacuum tubes who said[1] that "bei constantem Druck ist für ein und dasselbe Gas die Strahlung der Stromstärke proportional, und weil dies nicht nur für die Gesammtstrahlung, sondern auch für einen bestimmten Theil derselben gilt, so ist die spectral Vertheilung der Energie bei constantem Druck von der Stromstärke unabhängig." To be sure, the case of the Arons lamp is not exactly similar to a vacuum tube. The condition here is that of a saturated vapor in contact with its liquid phase, so that with the changing temperature the pressure in the tube changes as well. As the current is increased the temperature of the electrodes should increase and consequently the pressure in the tube should rise. According to the authority quoted the efficiency falls[2] with an increase of the pressure. If our measurements are correct the efficiency rises slightly under these conditions. In any event there is a field here which merits further and more thorough investigation.

The following are a few of the more common light sources and their radiant efficiencies, which were measured by this general method:[3]

Source.	Observer.	Efficiency.
Illuminating gas, argand burner.	Rogers.	0.0161
Incandescent electric lamp.	Merritt.	0.060
Arc light.	Tyndall.	0.104
Acetylene.	Stewart and Hoxie.	0.105
Geissler tubes.	Staub.	0.320
MERCURY ARC.	Geer.	0.409 to 0.479

From these figures and the full data given in Table II., it is seen that the mercury arc is quite remarkable. It has the highest known radiant efficiency. It is to be remembered, however, that these results indicate the efficiency only of that part of the radiation from the mercury arc which was transmitted through the glass tube within which the arc was formed.

[1] Wied. Ann., 48, 509, 1893.
[2] Wied. Ann., 48, 530, 1893.
[3] Nichols, PHYS. REV., 11, 221, 1900.

When one recalls that the spectrum of mercury is a line spectrum it is to be inferred from the efficiency values that some well-defined lines or bands are to be found in the region of the infra-red. Indeed the high efficiency here recorded may in part be due to the presence of energy of such large wave-length that the glass walls of the tube absorbed the waves, and, therefore, they were not taken account of in this method of determining the efficiency. The high heating of the walls of the tube may, at least to a slight extent, be ascribed to this cause. Several lines were predicted by Kayser and Runge,[1] but they have not been found as yet, and, so far as the writer is aware, nothing has been written which includes a systematic study of this portion of the mercury spectrum. In the near future it is purposed to publish the results of an investigation in this field.

In conclusion, it is with pleasure that sincere thanks are expressed to Prof. E. L. Nichols and to Prof. E. Merritt for the encouragement and many valuable suggestions which were given in the course of this work.

CORNELL UNIVERSITY, ITHACA, N. Y.,
November 15, 1902.

[1] Wied. Ann., 43, 405, 1891.

THE CHANGE OF VOLUME IN CLARK AND CADMIUM CELLS AND ITS RELATION TO CHANGE OF ELECTROMOTIVE FORCE DUE TO PRESSURE.

By Rolla R. Ramsey.

WHEN a Clark or Cadmium cell is put under pressure its E.M.F. is increased, as I have shown in a previous paper.[1] Since if the current is sent backwards through the cell a greater amount of energy is required to maintain the current constant in the case when pressure is applied, than that required when the cell is not under pressure, one would be led to expect that the volume of the cell was increased or that energy was used up in overcoming pressure.

Gilbault[2] has calculated this change in certain cells by means of a large number of measurements of densities of different per cent. solutions of the salt contained in the cell. It seemed to me to be interesting to measure the actual change and to compare this value with the value obtained by theoretical calculation.

Theoretical.—Suppose a cell whose E.M.F. is E, at zero pressure to be placed under a pressure, P say, and the E.M.F. be found to be increased by an amount, e. If in the first place a current i is allowed to pass through the cell the energy developed is

$$Eit,$$

or

$$EQ.$$

where Q is the quantity of electricity.

The same amount of energy would be used up in overcoming the E.M.F. of the cell if the same quantity of electricity were forced backwards through the cell. Place the cell under pressure

[1] Phys. Rev., Vol. 13, p. 1, 1901.

[2] Lum. El., Vol. 42, pp. 7, 63, 175, 220, 1891.

and force the same quantity backwards through the cell and the energy used in overcoming the E.M.F. of the cell is,

$$(E + e)Q,$$

or

$$EQ + eQ.$$

Since the first term is the energy required to overcome the ordinary E.M.F. of the cell, the second is the extra required due to the fact that the cell is under pressure, or the amount used up in external work in overcoming pressure (unless the nature of the electrolyte is changed by the pressure). This would require a change in volume. The external work in overcoming pressure would be,

$$Pdv.$$

This quantity should equal the added quantity of energy

$$Pdv = eQ.$$

It will be apparent that when e is positive the volume of a cell will increase when current is forced backward through the cell of will decrease when allowed to flow in the usual manner.

Knowing e, Q, and P, dv can be calculated.

For Clark cell:

Let $e = 11.6 \times 10^{-6}$ volts or 1,160 C.G.S. units, the increase of E.M.F. per atmosphere pressure.

$Q = 1$ C.G.S. unit quantity.

$P = 1$ atmosphere, or 1,050,000 dynes.

$$dv = \frac{eQ}{P},$$

$$= \frac{1{,}160 \times 1}{1{,}050{,}000} = .0011 \text{ cu. cm. per C.G.S. unit quantity,}$$

or $dv = .11$ cu. millimeter per coulomb.

For cadmium cell:

$e = 7.6 \times 10^{-6}$ volts.

$dv = .072$ cu. millimeters per coulomb.

Apparatus and Methods. — The method of measuring the change of volume was to observe by means of a cathetometer, the rise or fall of the liquid in a capillary tube which was attached to the cell. The cell was connected in series with four to seven gravity cells and an instrument for measuring current. The cell was made of glass tubing in the **H** form, Fig. 1. The **H** was blown and the electrodes placed as directed, in the case of the Clark cell, by Kahle;[1] in the case of the cadmium cell by Jaeger and Wachsmuth.[2] To one stem of the **H** a stop-cock was fused to the other a capillary stem of known cross-section. (In later cells the stem was heated and drawn to a capillary and the diameter measured afterwards by cutting the tube in two and placing under a micrometer microscope.) The cell was now filled through the stop-cock with the saturated electrolyte. By means of the stop-cock the electrolyte could be kept at any desired height in the tube. The cathetometer was one made by the Société Genevoise reading to $\frac{1}{50}$ millimeter. For current measurement a tangent galvanometer was used at first. In the later observations a Weston mil-ammeter was found to answer all requirements. Several forms of voltameters and electrolytic ammeters were tried but were found to be useless for the work.

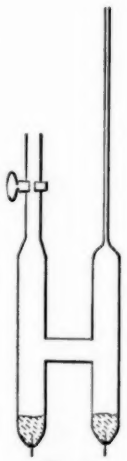


Fig. 1.

The apparatus was set up in a basement room. A thermostat was not attempted. To avoid rapid changes of temperature the cell was immersed in a bath of coal oil, which was immersed in a six-gallon jar of water. The jar was placed in a wooden box and packed with excelsior. By this means the temperature changes were not rapid, but there were variations of a degree or more from day to day. Attempts were made at first to run the current through the cell several days at a time and thus to get a large change in volume. This failed for two reasons. After the current had been running for some time, from a half hour to three hours, depending upon the size of the electrodes, the cell would polarize,

[1] Wied. Ann., 51, p. 203, 1894.
[2] Wied. Ann., 59, p. 575, 1896.

rendering the current intermittent, making the readings of the ammeter uncertain. Electrolytic ammeters were substituted, but the observations were uncertain on account of the temperature variations. Even after the coefficient was known the largest calculated change of volume fell within the limits of errors of the temperature coefficient. In one case the cell was packed in ice but the index gradually rose in the tube. This change was comparable to the change due to the current (the current strength being very small after polarization of the cell). The probable cause of this apparent change of volume was the aging of the glass of which the cell was composed. The best results were found to be obtained by short runs with the temperature as nearly constant as possible. Since the changes of volume were small and the temperature variable, the accuracy was not as great as was hoped to be obtained.

The readings were taken in the following order: The reading of the cathetometer was noted, the current started and readings taken at stated intervals, every minute or two. As soon as the ammeter began to show fluctuations the current was broken and the height of the index again noted by means of the cathetometer.

TABLE I.

July 26. *Cell No. IV.*

Time.	Temp.	Height.	Current in Milliamperes.
5.42 p. m.	0°	35.344	1.5
44			1.53
46			1.48
47		35.260	
48			1.4
49		35.240	
50			1.39
52			1.37
55		35.180	1.32
58			1.2
59		35.100	1.0
$dh = 2.44$	millimeters.	$dv = .254$ cu.	millimeter. $Q = 1.48$ coulombs.

Table I. contains a set of readings which will serve as as ample. The quantity of electricity was obtained from the area of a curve plotted with time as abscissas and current as ordinates. The current always

fell on one half or less of its initial value before the polarization fluctuations set in. These fluctuations were quite erratic. At times the galvanometer would drop to zero for an instant, even with seven cells on. In one case a large number of cells were connected on and the volume change became erratic. Hydrogen bubbles were found in the cell afterwards. The probable cause of the polarization is the small solubility of the depolarizer, mercurous sulphate. The solubility of mercurous sulphate being, according to Dolezalek,[1] .05 per cent. The E.M.F. of the cell as shown by means of a potentiometer was lowered when polarized. In the case of a Clark cell 1.417 volts at one time. After standing a few hours the cell regained its initial E.M.F. In one case after a continuous run of a week, upon resting 24 hours a hasty comparison showed the E.M.F. to be 1.425 volts at 24.4° temperature. The E.M.F. should be 1.421 volts, assuming Jaeger's[2] values. The comparison was made with a cadmium cell assuming Jaeger's values as found upon the same page.

Results.—Table II. contains a tabulated list of the various sets of observations upon Clark cells.

TABLE II.

Clark Cell.

Date.	Cell.	Temp.	Cross Section in sq. mm.	*dh.*	*dv.*
Jan. 25	I	16.0°	1.11	.1 mm.	.111
April 21	II	19.6	1.11	1.54	1.72
21	II	19.6	1.11	3.02	3.37
22	II	19.6	1.11	1.2	1.34
May 31	III	21.7	.368	.76	.276
June 3	III	22.6	.368	.40	.147
12	III	23.3	.368	.16	.054
13	III	23.8	.368	.42	.154
16	III	23.4	.368	.22	.081
July 26	IV	0	.104	2.44	.254
28	IV	0	.106	.16	.017
29	IV	0	.107	.46	.049
Aug. 1	IV	0	.111	.24	.026
1	IV	0	.111	.88	.097

[1] Jaeger, Die Normalelemente, p. 10.
[2] Jaeger, Die Normalelemente, p. 118.

TABLE II.—*Continued.*

Approx. Curr. Milliampere.	Direction.	Time.	Q Coulombs.	dv per Coulomb.	
				Obs.	Calc.
.18		81 min.	.872	.127	.11
.12		180	13.	.132	
		37	30.5	.111	
		7	5.8	.232	
6.3		7	2.68	.104	
		8	3.87	.038	
		7	3.28	.018	
		5	2.3	.067	
		3	1.31	.062	
1.45		17	1.48	.171	
1.15		4	.276	.062	
.635	Reversed.	14	.531	.092	
.86		8	.413	.064	
.74	Reversed.	10	.443	.218	
				Mean .105	

Table III. contains the work done on a cadmium cell. All the results on this cell fell below the calculated value. Judging from the general behavior of the cell I would say that this was probably due to a bubble of air in the cell. Owing to the crowded condition of the department it is necessary to tear down my apparatus, so I give my results as they now stand.

TABLE III.

Cadmium Cell.

Date.	Cell.	Temp.	Cross Section sq. mm.	dh.	dv.
Sept. 2	V	22.°6	.160	.8 mm.	.128 cu. mm.
Sept. 2	V	22.°5	.160	.14	.022
Sept. 4	V	22.°	.160	.10	.016
Sept. 5	V	21.°5	.160	.5	.080

Approx. Curr. Milliampere.	Direction.	Time.	Q Coulombs.	dv per Coulomb.	
				Obs.	Calc.
1.5		30 min.	2.37	.054	.072
1.9	Reversed.	5	.57	.039	
1.7	Reversed.	3	.31	.052	
1.3		20	1.64	.048	
				Mean .048	

The observations marked "reversed" are taken with the current forced backwardt hrough the cell. The results from these observations are the same as those obtained when the current is flowing forward through the cell, showing that the effect is reversible.

PHYSICAL LABORATORY, UNIVERSITY OF MISSOURI,
COLUMBIA, MO., Sept. 16, 1902.

ON THE DIMENSIONS OF LARGE INDUCTANCE COILS.

BY JAMES E. IVES.

IT is sometimes desired to construct large coils of known self inductance. Having recently had occasion to calculate the inductance of a number of such coils, I have thought it desirable to record the results.

The inductance of a coil of rectangular cross-section may be calculated, to about one per cent., from Maxwell's formula:

$$L = 4\pi an^2 \left[\log_e \frac{8a}{r} + \tfrac{1}{12} - \tfrac{4}{3}\left(\theta - \frac{\pi}{4}\right)\cot 2\theta \right.$$

$$\left. - \tfrac{1}{3}\pi \operatorname{cosec} 2\theta - \tfrac{1}{6}\cot^2\theta \log_e \cos\theta - \tfrac{1}{6}\tan^2\theta \log_e \sin\theta\right]$$

where (see figure)

L = inductance of coil,

a = mean radius of coil,

n = number of turns in coil,

r = diagonal of the cross-section,

θ = angle made by diagonal with lower edge of the cross-section.

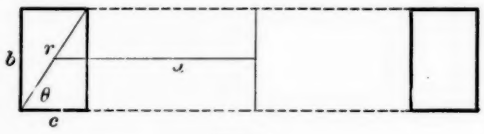


Fig. 1.

In this formula only the first term of a series is used. If greater accuracy is required the second term must be added.[1]

This expression may be written in the form

$$L = 4\pi an^2 \left[\log_e \frac{8a}{r} - f(\theta)\right],$$

[1] See PHYSICAL REVIEW, Vol. XIV., p. 297, 1902.

where $f(\theta)$ is a term depending only upon the shape of the cross-section. For a square cross-section, $f(\theta) = .83$. For a cross-section in which $\theta = 73°$, $f(\theta) = .72$.

The inductances of seven coils of varying dimensions, constructed with No. 18 [1] (Brown and Sharpe gauge) copper wire, were calculated by this formula, and the results are given in the accompanying table. The wire was double cotton covered, and the centers of the wires were assumed to be one twentieth of an inch apart. Coils I.–VI. were wound with 5,000 feet of wire, and coil VII. with 10,000 feet. Only two values of θ were used, viz., $\theta = 45°$ and $\theta = 73°$. It may be noted, that for the same θ, the cross-sections, though not all of the same size, are all similar. Coils III. and VII. have the dimensions for maximum inductance for 5,000 and 10,000 feet, respectively, of No. 18 wire. The dimensions of a coil of maximum inductance for a given length of wire are found by taking $\frac{2a}{b} = 3.7$, where a is the mean radius of the coil, and b is the length of a side of the *square* cross-section.[2]

TABLE I.

	Length of Wire in Feet.	Number of Turns.	a in Inches.	b in Inches.	c in Inches.	θ	Inductance in Henries.	Remarks.
I.	5,000	2625	3.13	2.75	2.75	45°	.72	
II.	5,000	2625	3.75	5.00	1.50	73°	.85	
III.	5,000	2230	4.36	2.36	2.36	45°	1.05	Maximum for 5,000 feet.
IV.	5,000	2230	4.36	4.30	1.29	73°	.92	
V.	5,000	1940	5.00	2.20	2.20	45°	1.04	
VI.	5,000	1940	5.00	4.00	1.20	73°	.93	
VII.	10,000	3530	5.50	2.97	2.97	45°	3.33	Maximum for 10,000 feet.

From the values given in the table it is evident:

1. That a coil of maximum inductance must have a square cross-section.

2. That the inductance of a coil, with a given length of wire, increases rapidly, as the mean radius is increased, up to the maxi-

[1] No. 18 wire has a diameter of .0403 inch.

[2] See Maxwell, Electricity and Magnetism, § 706.

mum inductance, and then, as the mean radius is increased still further, decreases very slowly. Therefore it is better to make the mean radius too great than too small.

3. That for coils of maximum inductance, the inductance increases very rapidly as the length of wire used increases; not quite as fast as the square of the length.

UNIVERSITY OF CINCINNATI,
October, 1902.

A CONVENIENT STORAGE BATTERY INSTALLATION.

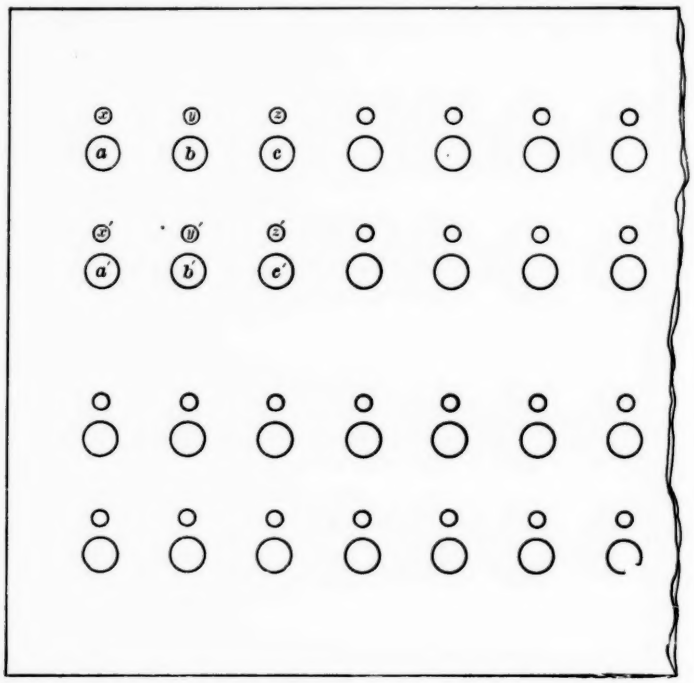
By W. J. Humphreys.

A GOOD storage battery is justly regarded as one of the most essential things in the equipment of a physical laboratory. Its value, however, both as a reliable and convenient source of electric currents and as an instrument for instruction, depends largely on the way in which it is set up; and while it would seem that there could be no trouble whatever in adapting so simple a thing to the use of students, I suspect that others, like myself, have found the problem not wholly free from difficulties; at least such was my own experience when I undertook, some four years ago, to so fit up a storage plant that it would meet the various needs, other than those of lighting and power, of our new laboratory. Nor was I able to get helpful suggestions from any of several sources to which one would naturally turn for such directions. But I did obtain much kind and valuable information from Professor Hering who had just completed an excellent storage installation in the physical laboratory of the Johns Hopkins University. I should probably have tried to duplicate his work in every particular but for the fact that the means at my disposal and some of the objects in view compelled modifications and simpler plans. The mounting finally used cost but little, is convenient in every particular and suited to teaching and general laboratory work. A test of four years has not suggested desirable changes, and besides it has so commended itself to others that it is now adopted in several institutions. I therefore, in response to many requests, offer a brief description of its essential features, trusting that in this way I may serve some one who has occasion to install a storage plant for similar purposes.

The battery I shall describe consists of thirty-six cells of the "chloride accumulator," type E, with glass jars, but evidently the same plans can be used for any number and any type of cells.

The frame on which these cells are placed is accessible from all sides, is eight feet four inches long, six feet high and one foot six

inches wide, and is divided into three shelves, each carrying one dozen cells. The cross-sections of the corner posts and of the railings along each shelf are two and three quarter by three and one half inches. The frame is still further strengthened by an upright at the middle of each side, and the whole is mounted on six heavy glass insulators, one under the foot of each post. The paint with which the entire woodwork is covered is the kind known as "tileite," selected because of its resistance to acids and alkalies. Each cell



is separately mounted in a wooden tray about three quarters of an inch deep that stands on three small glass insulators. The trays are painted with asphalt varnish and filled with ground mica of medium fineness, the flakes varying in area from one to three or four square millimeters. Still further insulation is secured by covering the cells with vaseline which prevents any liquid that might get on the sides from forming a continuous layer. The mica is intended to absorb stray drops of water or acid which will be taken up by the top layers, leaving the lower ones still dry and non-conducting. Good white sand would probably do nearly as well as the mica.

It has been suggested that carbonate of soda be added to the sand or mica since this would unite with the acid, should any get on it, and produce dry non-conducting sulphate of soda, but there is a chemical action between the carbonate of soda and the mica which, though it takes place slowly, soon produces a damp, unsatisfactory mass that can do no good and is likely to do much harm.

The liquid in each cell is covered with a layer, about a quarter of an inch thick, of paraffine oil. This prevents excessive evaporation during very dry weather, and absorption of moisture that might cause disastrous overflowing when the air is particularly damp. Besides, the disagreeable and corrosive acid spray, caused by the bursting of bubbles while the cells are being charged, is well nigh wholly avoided. Apart from the comfort this gives it makes it safe to have apparatus near the battery, avoids the necessity for extra ventilation, prevents fouling of the battery frame and preserves the insulation.

The above precautions against leakage may be excessive, but they are easily made, and I have had no trouble whatever from imperfect insulation during a constant use of the battery for four years, though it is placed in a small basement room that has often been very damp, nor has it been necessary to renew or clean any of the insulating materials.

Two large copper wires, of very low resistance, run from each cell to the switch board which is placed just beyond a partition near one end of the battery frame. These wires are soldered to the terminal lugs of the elements, and thus the trouble due to corroded and bad connections is avoided. Each wire is also soldered to a fuse block conveniently located above the switch board. According to my experience it is far better to use fuse links provided with flat copper terminals, since fuse wires, when clamped down with screws, frequently get loose and give bad connections. The links seem to be free from this objection.

The switch board which lies horizontally in a suitable frame, consists of a close-grained white marble slab, two inches thick, twelve inches wide and forty inches long. This slab is drilled through with holes the proper size to take the wires from the battery that come up from beneath, bend over and terminate in nearby larger holes about three quarters of an inch deep, that contain mercury.

I will say for the benefit of those who have occasion for the first time to drill marble, that it is an exceedingly easy thing to do. I use for this work a sensitive drill press and ordinary twist drills. It is only essential to use plenty of water as a lubricant, but of course it is also desirable to keep the drills reasonably sharp.

For the sake of compactness and convenient spacing these holes are arranged in two double rows as illustrated in Fig. 1, which shows a part of the slab as laid off or drilled, but without connections. The cups, a, b, c, and so on, are connected by wires through x, y, z, ..., say to the positive sides of the cells, while a', b', c' and so forth, are similarly connected through x', y', z', ..., to the negative sides of the corresponding cells. In this way the slab, by its pairs of mercury cups, becomes a simple representative of the entire battery, one that any beginner can understand and by means of which he can readily test the voltage of all sorts of combinations.

To connect the cells in multiple or series straight heavy wires with their ends bent down are used. The mercury cups are so spaced that the wires connecting them in multiple, that is, of sufficient length to unite a and b say, are too short to connect the positive and negative sides of a cell, while those used for joining in series, and therefore reaching from a to b', are too long to connect opposite sides of the same cell. In this way the chances of short-circuiting are materially reduced, a feature by no means undesirable in a laboratory battery.

The wires of the various laboratory circuits are soldered to a row of fuse blocks above the switchboard, and connection between them and the mercury cups is secured by means of flexible cords, also soldered to the fuse blocks that terminate with a short section of solid copper. I used, for these terminals, heavy wires about an inch long, drilled axially deep enough to admit the ends of the flexible cords, which, of course, were soldered in place. As a matter of convenience each circuit is correspondingly numbered above the switchboard and at the terminal end.

A rheostat, a circuit breaker and an ammeter in the charging circuit, and a voltmeter for testing the cells, all close beside the switchboard, complete the outfit.

UNIVERSITY OF VIRGINIA, July, 1902.

NOTE ON THE SELECTIVE ABSORPTION OF FUCHSINE AND CYANINE.

By William W. Coblentz.

IF we except the investigations of materials suitable for prisms, our knowledge of the selective absorption in the infra-red region of the spectrum is rather limited.

A knowledge of the absorption spectrum of fuchsine and cyanine is of twofold interest: (1) the work of Pflüger[1] on the anomalous dispersion of solid dyestuffs shows that for cyanine and fuchsine there is a single absorption band extending from .45 μ to .65 μ; (2) fuchsine and cyanine are chemically different in composition. Fuchsine ($C_{20}H_{19}N_3HCl + 4H_2O$), contains a methyl group, while the chemical constitution of cyanine, ($C_{30}H_{39}N_2I$), is unknown. Nietzki[2] says of it that "Possibly the cyanines possess a structure analogous to that of the phenylmethane dyestuffs," *e. g.*, fuchsine.

In the present work the radiometer rock-salt apparatus previously described[3] was employed.

The cyanine film was obtained by melting the crystals on a plate of rock salt. Considerable difficulty was experienced in obtaining a film of fuchsine which was thin enough, yet at the same time would not crack and peel off the rock salt. The method adopted for obtaining a thin film was to reduce the fuchsine crystals to a fine powder, add a little alcohol to form a thick paste, and apply it to the rock salt. After it had dried, it was reduced to the proper thickness by wiping off the surface with a cloth dampened with alcohol.

The percentage of transmission was obtained by noting the deflection of the radiometer vane caused by the light passing through the rock salt and film, and also by that which passed through a clear part of the same plate.

[1] Pflüger, Wied. Ann., 65, p. 173, 1898.
[2] Nietzki, Chemie der Organischen Farbstoffe, p. 262, 1901.
[3] Phys. Rev., Vol. XVI., p. 35, 1903.

Two cyanine films, thickness .05 mm. and .182 mm., and one fuchsine film thickness .025 mm., were examined.

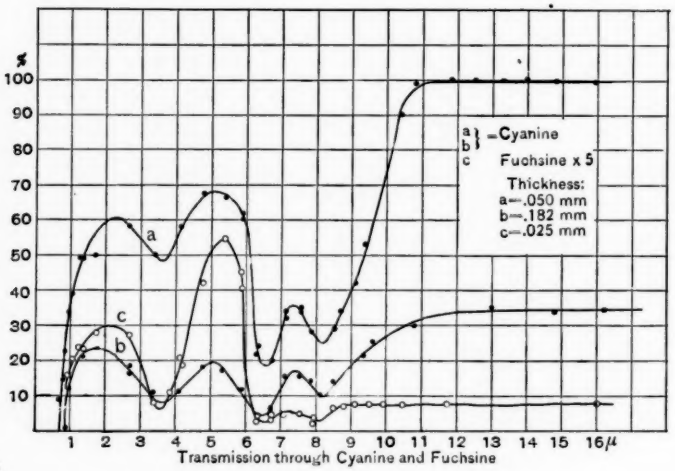


Fig. 1.

The similarity of the transmission curves, Fig. 1, of these two substances is very striking. The transmission of a film of cyanine, 0.05 mm. thick, rises suddenly from zero at 0.7 μ to 60 per cent. at 2.3 μ, where a shallow absorption band begins and extends to 4.5 μ — maximum at 3.5 μ. At 5.5 μ a deep double absorption band begins and extends to 9.5 μ. The first maximum is at 6.5 μ while the second is at 8.2 μ. Beyond 10 μ to 17 μ the absorption is constant, and for this film is zero.

As a whole, the absorption of fuchsine is far greater than cyanine, so that a film 0.025 mm. had to be used. In Fig. 1 the ordinates of the fuchsine curve are magnified 5 times. Beyond 5 μ the results represent the mean of a number of readings, repeated on different days. In the fuchsine curve the mean and the single readings have been plotted for several wave-lengths.

Fuchsine has three absorption bands whose maxima coincide with those of cyanine. Beyond 9 μ the absorption again becomes constant. The transmission for the different parts of the spectrum is given in Table I.

TABLE I.

Transmission through cyanine and fuchsine.

Wave-Lengths in μ.	Cyanine.		Fuchsine	Wave-Lengths in μ.	Cyanine.		Fuchsine.
	$a = 0.05$ mm.	$b = 0.182$ mm.	$c = 0.025$.		0.05 mm.	0.182.	0.025.
.7μ	9			6.75	20	5.6	0.90
.8	14			7.14	34	15.5	0.75
.9	23.5	12	3.3	7.54	35	15.3	0.85
1.0	34	21		7.93	28	14.5	0.73
1.1	39		4.0	8.12		10	
1.4	48	23	4.6	8.50	29	14	1.30
1.75	50	18.5	5.7	8.70	34		1.30
2.7	58		5.4	9.1	42	18	1.50
3.45	50	10	1.6	9.4	53	22	1.40
4.17	65	10.9	4.0	10.45	90		1.46
4.82	67	18.5	8.4	10.8	99	30	
5.42	63	17	11.	11.8	100	35	1.50
5.90	62	12	9.	12.5	100		
6.36	24	9.9	0.72	16.+	100	34	1.40

Pflüger[1] has found the constants a, g and d of cyanine in the Kettler-Helmholtz dispersion formula.[2] Using the upper values of g and d, and finding the extinction coefficient,

$$\varkappa = \frac{1}{l}\frac{\lambda}{4\pi}\frac{1}{\log. e}\log\frac{I_0}{I_e},$$

for the first absorption band of cyanine, at $\lambda = 6.5\,\mu$, the index of refraction is 1.43. In Table II. all the indices except the last one are due to Pflüger.

TABLE II.

$\lambda = .44\,u$	$n = 1.69$
.57	1.48
.62	1.94
.64	2.10
.65	2.23
.66	2.19
.67	2.08
6.50*	1.43

[1] *L. c.*

[2] Dispersion formula:

$$n^2 = \kappa + a + \frac{D\lambda^2(\lambda^2 - \lambda_m^2)}{(\lambda^2 - \lambda_m^2)^2 + g^2\lambda^2} \quad g = \begin{cases} .0303 \\ .028 \end{cases} \quad D = \begin{cases} .069 \\ .041 \end{cases} \quad \lambda_m^2 = .380 \quad a = 1.972.$$

Julius[1] examined a large number of compounds, and found that all those containing the methane group have a maximum absorption band at $\lambda = 3.45\,\mu$ and a second band between 8 and $9\,\mu$. But his prism calibration is wrong beyond $5\,\mu$, since he used the straight line extrapolation from this point, so that the second band lies between 6 and $8\,\mu$. The work of Abney and Festing[2] on the absorption spectra in the infra-red also shows that the methyl group has a distinctive selective absorption.

In Fig. 1 the maximum of the first absorption band is indicated at $3.55\,\mu$. After the curves had been sent to the engraver this region of the spectrum was reëxplored more thoroughly, at every $0.1\,\mu$, with the result that the maximum occurs at $3.5\,\mu$. Table III. gives the transmission.

TABLE III.

Wave-Lengths in μ.	2.5	2.93	3.14	3.30	3.38	3.49	3.56	3.68	3.92	4.05	4.65
Transmission.	61	56.7	48.3	42.8	40.8	39.8	40.3	41.2	47.8	53	63

Considering the similarity of the absorption bands of fuchsine and cyanine, and the experiments of Julius, one is tempted to assume that there is more than a mere possibility of a relation between the chemical constitution of cyanine and fuchsine, *i. e.*, that cyanine has a structure analogous to that of the phenylmethane dyestuffs.

Cyanine contains one atom of iodine. But there is no similarity between the curves[3] of cyanine and iodine, and like Abney and Festing, one concludes that: "The detection of the presence of iodine in a compound is at present undecided."

PHYSICAL LABORATORY, CORNELL UNIVERSITY,
June, 1902.

[1] Julius, Beiblätter, 17, p. 34, 1893.
[2] Abney and Festing, Phil. Trans., 172, p. 887 (1881).
[3] Iodine curves are given in PHYS. REV., Vol. XVI., No. 2, 1903.

THE SPECTRAL ENERGY CURVE OF THE ACETYLENE FLAME.

By G. W. Stewart.

IN a previous paper[1] on this subject, I used a modification of Paschen's method of obtaining the actual distribution of energy in a pure spectrum from the observations taken with a spectrometer and radiometer or bolometer. This modification proves to be a mistake, and, since the correct curves for the distribution of energy in the spectrum of acetylene are of some service, I have redrawn the curves, using the proper method of correction. Moreover, in view of the fact that this modification of Paschen's method has received favorable comment from some quarters, I shall point out the error made in the previous paper and at the same time present experimental proof of the correctness of his formula.

There are two articles, one by Runge[2] and the other by Paschen,[3] which give an accurate formulæ for the correction of observed curves in spectral energy work. The two equations which they present are identical save that Runge has a^2 where Paschen has a. This, together with the fact that Runge says, "Die Wirkung auf den Bolometerstreifen wächst daher annahernd proportional ab" (that is, a^2 when the bolometer strip b equals the spectrometer slit width a), led me to the hasty conclusion that the two equations were not the same, one of them stating that the energy falling on the radiometer or bolometer strip is approximately proportional to the square of the slit width, and the other that it is approximately proportional to the slit width. A closer examination of Runge's article shows that his formula is identical with Paschen's; that he defines another term in the formula, $f(x)$, in such a way that his $af(x)$ is the same as Paschen's $f(x)$; and that the above quotation is true,

[1] Physical Review, Vol. XIII., No. 5, November, 1901.

[2] Zeitschr. für Math. und Phys., 42, 1897, p. 205.

[3] Annal. der Phys., 60, 1897, p. 712.

if one bears in mind that he imposes the condition that the spectrometer slit width, a, in wave-lengths is the same for all wave-lengths, *i. e.*, is a constant in the formula.

The errors made in my discussion in the article already cited are found on pages 275 and 276. On page 275 the statement, "In different parts of this spectrum, the slit has different widths when expressed in wave-lengths," is true, but one should at this point consider only the actual width, which is constant. On page 276 occurs the sentence, "If the radiometer slit is at x, then an image of the spectrometer slit due to the wave-length x will fall entirely within the radiometer slit, and the intensity of this image is $af(x)$."

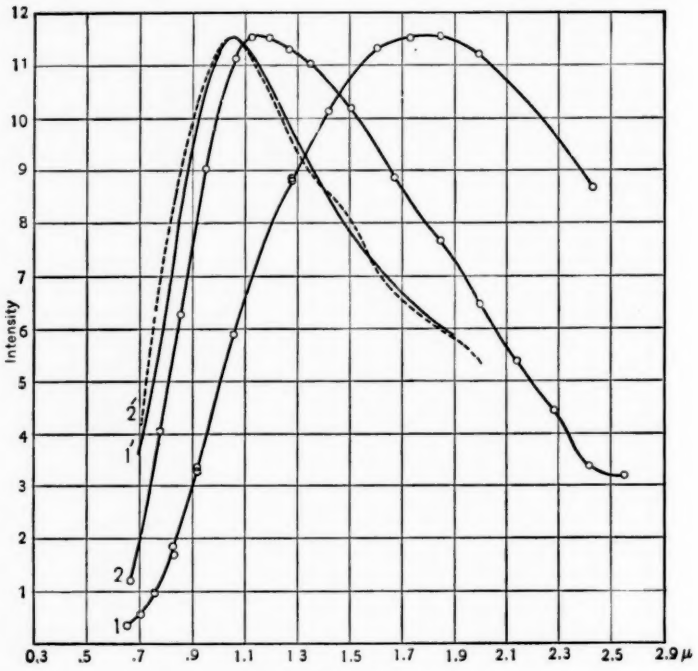


Fig. 1.

If a were the actual width in centimeters, say, the intensity would be proportional to $af(x)$ or to $f(x)$, a then being constant. But a is the slit width in wave-lengths. Hence instead of $af(x)$ I should have written $f(x)$. This change makes the resulting equations identical with Paschen's.

In order to demonstrate experimentally the correctness or incorrectness of Paschen's method, I found the distribution of energy of the acetylene flame using a rock-salt prism, angle 59° 47′ 53″, in place of the fluorite, which was used in the previous work. The apparatus otherwise was precisely the same as before.

The proper correction applied to the observed fluorite and rock-salt curves should give the same result. In Fig. 1 curves 1 and 1′ are the observed and corrected curves, respectively, when rock-salt was used, and 2 and 2′ are those obtained with the fluorite. Curves 1′ and 2′ will be seen to agree very closely, particularly when one considers the very great difference in the observed curves.

The water emission bands at 1.46 μ and 1.90 μ do not appear in curve 1′ because enough observations were not taken to bring them out. In fact the curve represents one of the two series of observations which were made. This, together with the small deflection in the region 0.7 μ to 1.0 μ would account for the discrepancy in that portion of the curve. The refractive indices of rock-salt used are those of Rubens.[1]

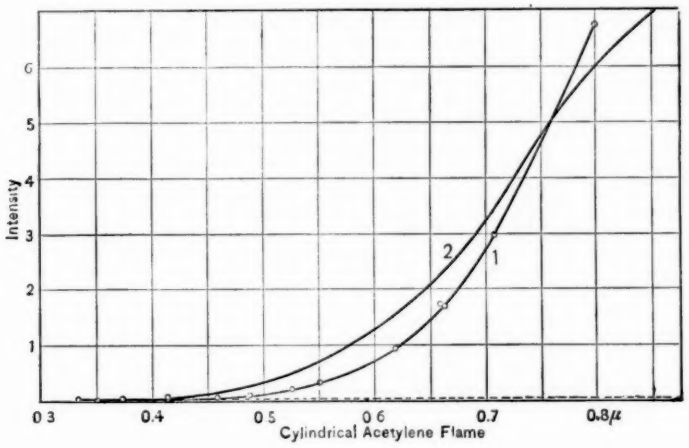


Fig. 2.

The new curves for the distribution of energy in the spectrum of acetylene, when the correction has been made by the method of Paschen, are shown in Figs. 2 and 3, curves 2. In making the

[1] Kayser, Handbuch der Spectr., 1 Band, p. 371.

correction only the first two terms of Paschen's formula was used, viz.,

$$af(x) = F(x) - \tfrac{1}{6}F_1(x).$$

In a recent article[1] Ångström finds the efficiency of the acetyleen flame to be 5.5 per cent. The efficiency as given by the ratio of the area of curve 2, Fig. 2, as far as 0.76 μ, to the total area, is 3.9 per cent. While the accuracy of this method in practice is questionable, yet in this case the observations in the visible spectrum were made with great care, as will be seen by Fig. 3. The errors

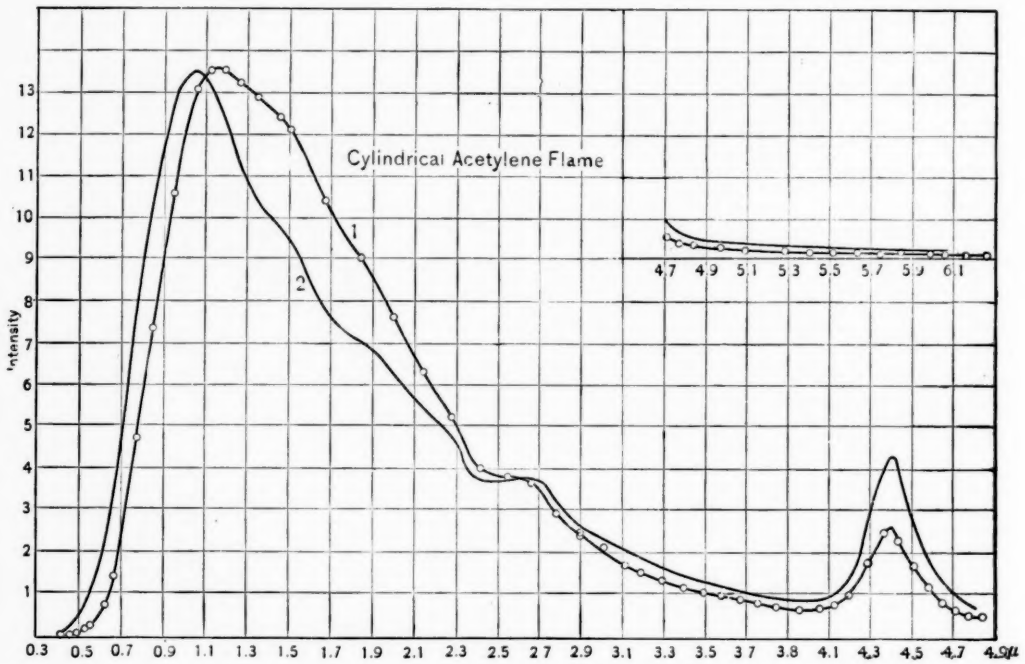


Fig. 3.

in the infra-red due to CO_2 and H_2O absorption increase the value of the efficiency. One is inclined to think, therefore, that the value 3.9 per cent. is none too small.

PHYSICAL LABORATORY, CORNELL UNIVERSITY,
November, 1902.

[1] Physikal. Zeitschr., 15 März, 1902, p. 257.

NEW BOOKS.

Light, a Consideration of the More Familiar Phenomena of Optics. By CHARLES S. HASTINGS, Professor of Physics in Yale University. New York, Charles Scribner's Sons, 1901.

A series of publications were prepared with the approval of the president and fellows of Yale University by a number of the professors and instructors and issued in connection with the bicentennial anniversary as a partial indication of the character of the studies in which the university teachers are engaged. This volume on light, by Professor Hastings, belongs to this series.

"There is a very large number of phenomena in the domain of optics which may be regarded as familiar, in the sense that all of them may be observed without the accessories, which are found only in the collections of philosophical apparatus characteristic of physical laboratories. To describe and explain this class of phenomena is the aim of this book."

The extensive subjects of spectroscopy and polarized light are excluded by the limitations which the writer has seen fit to impose upon himself. The phenomena of color sensations are treated rather briefly, because of the excellent available popular treatments of these phenomena. The chapter on atmospheric optics has been made quite extensive, in view of the fact that so little has been contributed to this subject during the last half century.

No branch of applied science, says Professor Hastings, has experienced a more remarkable revolution in recent times than that which the advance of theoretical optics has impressed upon the manufacturing optician. In the chapters on the telescope and on the microscope, Professor Hastings has explained the character and meaning of these recent improvements.

Professor Hastings has given us a book which is highly interesting and instructive, a book which must meet with the unqualified approval of every one who is interested in the wide dissemmation of knowledge.

W. S. FRANKLIN.

Lessons in Practical Electricity, Principles, Experiments and Arithmetical Problems. C. WALTON SWOOPE. Pp. 462. New York, D. Van Nostrand Company, 1901.

This is a revised and enlarged edition of "Lessons in Practical Electricity" published privately five years ago for use in the Spring Garden

Institute, Philadelphia. It contains much material, covering a wide field, beng intended as a student's book to be used not only as a general treatise on the principles of electricity and their experimental demonstration, but also as a manual in making practical measurements and calculations.

The book contains much that is concrete and has more in it of practical value than is found in most books of its class. Although generally correct, the statements are not invariably precise; as illustration, we may note the following:

"Self-induction is defined as the cutting of a wire by the lines of force of the current flowing through it. * * * With a steady current the induction is only momentary" (§ 294).

"On account of the reactance, a larger size of conductor must be used in alternating current circuits than when direct currents are used" (§ 297).

"(The reactance) is equal to the product of its inductance, the number of times the current flow is reversed per second and a constant 6.28" (§ 297).

In the last definition instead of number of reversals we should use number of cycles per second (one cycle consisting of two reversals). It seems unfortunate that the simple factor "2π" should be disguised as "a constant 6.28." F. BEDELL.

An Elementary Book on Electricity and Magnetism and their Applications. By DUGALD C. JACKSON and JOHN PRICE JACKSON. Pp. 482. New York, The Macmillan Company, 1902.

This book is inspiring. It is attractive in treatment and mechanical make-up and proves interesting reading not only for the beginner for whom it is intended but also for one already familiar with the subject matter. In the preface we are told "Every effort has been exerted to make it clear, forceful, and of strict scientific accuracy, though it is written in reasonably colloquial language." It is a pleasure to note the success of the authors in these particulars. To the reviewer it has been interesting to see how various subjects are now made clear in an elementary text-book, which a few years ago were matters for advanced students only; then these were matters for research; to-day they are every-day knowledge. F. BEDELL.

Standard Polyphase Apparatus and Systems. (Third Edition.) By MAURICE A. OUDIN. Pp. 282. New York, D. Van Nostrand Co. 1902. (*Received.*)

Electric Power Transmission. (Third Edition.) By LOUIS BELL. Pp. 625. New York, Electrical World and Engineer. 1901. (*Received.*)